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A LIFE CYCLE ANALYSIS AND ASSESSMENT OF CHEMICAL EMULSIONS

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A dissertation submitted to the Faculty of Engineering and Built Environment, University of the Witwatersrand, Johannesburg, in fulfillment of the requirements for the degree of Master of Science in Engineering

Johannesburg,2010

DECLARATION

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination in any other University

_____

Signature of Candidate

_____ day of _____ year _____

ABSTRACT

This study utilises the Life Cycle Environmental Management tool, Life cycle Assessment (LCA) to compare the overall environmental impact of the life cycles of three manufactured emulsions. The emulsions - Aquapel, Hi-phase/composite (liquid/solid rosin) - fulfil a specific function as a sizing agent in the cardboard box industry within the confines of South Africa. As the origins and use of these emulsions are different, the impact assessments of each were evaluated.

Using the Simapro Impact 2002+ assessment method, the *mid-point impact categories* show the most significant impacts in descending order to be Toxicity Impacts on terrestrial ecosystems, Respiratory Inorganics, Climate Change and Non Renewable Energy resources.

It would appear that toxicity impacts on terrestrial ecosystems, is the most significant impact. Emission of respiratory inorganics followed by effluent treatment, then electricity used in the emulsion process itself has the next highest contribution in all three processes. The higher contribution to respiratory inorganics by the process using liquid rosin is due to a relatively high contribution from the production of tall oil, a relatively energy intensive process. Climate change is the third most significant contribution. Non renewable energy resources for the Aquapel process shows the highest impact because of its raw material, wax. It is also based on a non-renewable energy resource, crude-oil, whilst the raw material for the Hi-phase/composite process, rosin, is bio-based.

When comparing the three emulsion processes according to the *Impact 2002+ damage or end point impact categories* the relative contributions of the processes shows the relatively close performance of the three processes. The liquid rosin process shows slightly higher potential damages in three out of the four damage categories. The explanation for the differences between the systems follows from the explanations given for the mid-point impact categories.

The sensitivity analysis for the *Aquapel emulsion process shows* negative impacts are produced in descending order for liquid effluent in the ecosystem and human health damage categories. For electricity and paraffin wax negative impacts in the human health and climate change damage categories. The best interventions to reduce life cycle damages is to reduce water and electricity consumption and if possible to find a substitute for paraffin wax.

For the *Hi-phase/composite liquid / solid rosin emulsion process shows* negative impacts are produced in descending order for liquid effluent in the ecosystem and human health / climate change and resources damage categories respectively. The electricity and steam used in both the liquid / solid process produce negative impacts in the human health and climate change damage categories. The best interventions to reduce life cycle damages for the rosin emulsion process are to reduce water, electricity and steam consumption.

In memory of my late dad

Ram Reddi

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LIST OF ABBREVIATIONS

APME	Association of Plastics Manufacturers in Europe
BAT	Best Available Technology/Technique
BUWAL	Swiss Bundesamt for Umwelt, Wald und Landschaft
CAIA	Chemical and Allied Industries Association
CF	Conservation Fund
CML	Centre for Environmental Studies
DALY	Disability Adjusted Life Years
DEAT	Department of Environmental Affairs and Tourism
DfE	Design for Environment
DWAF	Department of Water and Forestry
EMS	Environmental Management System
GWP	Global Warming Potentials
IPCC	Intergovernmental Panel on Climate Change
ISIC	International Standard Industrial Classification
ISO	International Organisation for Standardisation
LCA	Life Cycle Assessment/Analysis/Approach
LCC	Life Cycle Costing
LCE	Life Cycle Elements
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NOH	National Reuse of Waste Research Programme
PAF	Percentage Affected Fraction
PDF	Potentially Disappeared Fraction
RMME	Relative Mass Energy-Economics
SETAC	Society of Environmental Toxicology and Chemistry
TC	Technical Committee
UNEP	United Nations Environmental Program
VROM	Dutch Ministry of Housing, Spatial Planning and the Environment
WHO	World Health Organisation
WWF	World Wide Fund

CHAPTER 1: INTRODUCTION

The process industries and manufacturing organisations continually conduct studies exploring methods and ways to evaluate, improve and optimise the overall environmental impact of the manufacturing process and its products. The class of environmental consideration most relevant to this study is: Life Cycle Elements (LCE) – e.g. resource efficiencies, comparison of the consecutive stages of the value chain, from raw material extraction to product use, for overall optimisation (Loots, 2000).

For this study the process industry refers to the foundry industry and is defined as division 24 – Chemical Products of category D – Manufacturing of the United Nations (1998) registry of International Standard Industrial Classification (ISIC).

1.1 LCA Concept

The concept of life cycle was first discussed more than 20 years ago. A severe limitation to the wide application of the concept was related to the fact that, up until recently, there was no comprehensive methodology to facilitate the understanding of the process and provide the basic tools necessary to conduct the analysis in a rigorous and cost-effective manner (Ciambrone, 1997)

Modern methods for evaluating potentially negative environmental impacts involve the use of a variety of tools. The widely embraced ISO 14001 (clause 4 sections 4.1 & 4.2) is an excellent example of how various public and private entities are voluntarily approaching environmental management. This is particularly important in today's global economy combined with the requirements imposed by some countries on the production and use of "green" products.

A complete LCA process and stages, Figure 1.1 and Figure 1.2, begins with raw materials acquisition and follows manufacturing stages until the product is produced, used and discarded. According to ISO 14040, the methodology

involves a framework in which the goals and scope of the LCA are defined, inventory analysis and impact assessments formulated and the results interpreted.

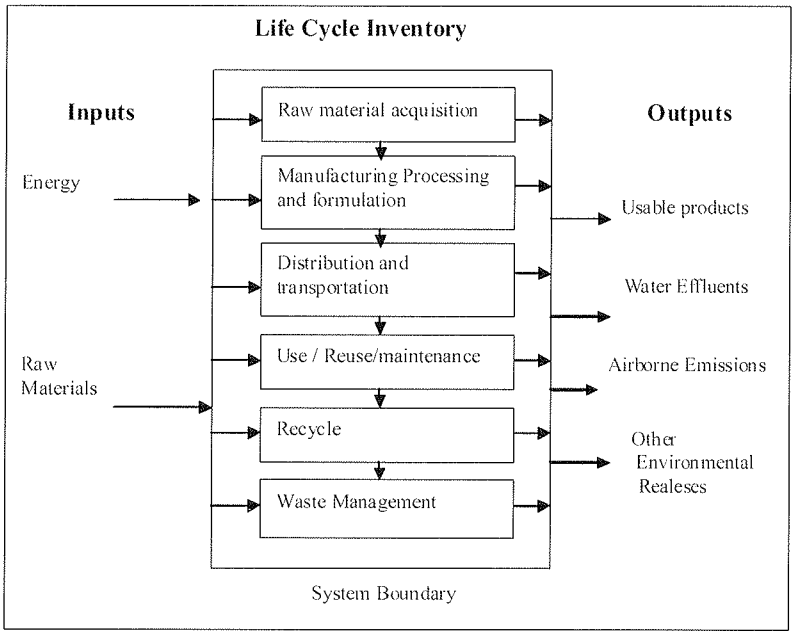

Figure 1.1: Inputs and Outputs for each stage in the life cycle must be collected (Source: SETAC 1992)

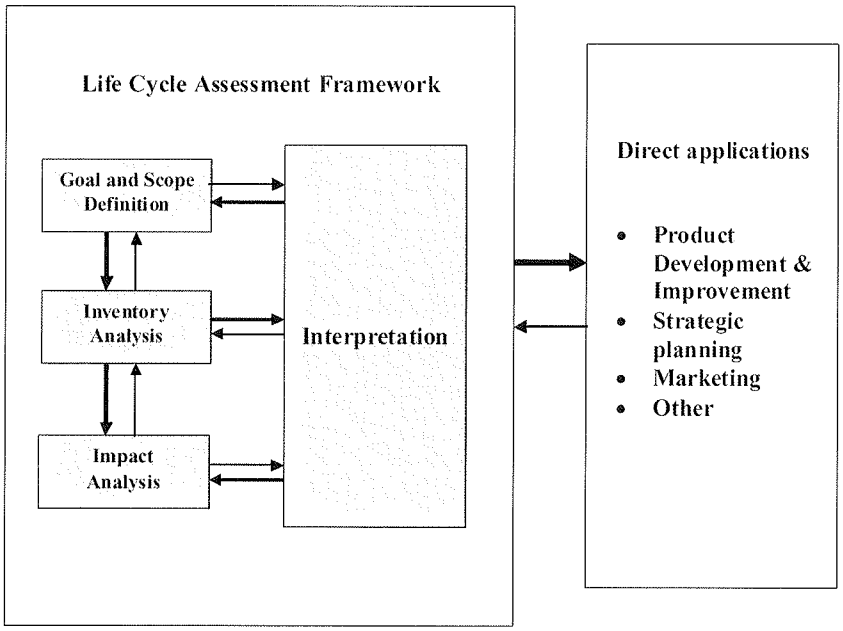

Figure 1.2: LCA Phases (Source: Figure 1 in ISO 14040: 1997).

According to Culaba & Purvis (1999), 'Environmental management systems are being increasingly adopted by companies to promote and demonstrate sound environmental practice. Such systems will include an evaluation of the environmental impacts of company operations, e.g. by means of an environmental audit or more detailed considerations related to manufacturing processes using LCA methods'.

The ISO 14040 concept of the LCA considers the environmental and potential impacts of a product or service system throughout its life – from raw material acquisition through production, use and disposal (from cradle to grave). There is no single method for conducting an LCA and the framework is made sufficiently broad to allow the study of wide ranging environmental practices.

Applications of LCA studies as identified by ISO14041 (1998) are achieved by conducting comparative LCA's between two or more products that perform the same function or hot spot identification where the major phases of environmental concern in the life cycle of the product will be identified. LCA's are only one of many decision support tools and other informative tools to aid in the making of decisions that may address many aspects not included within the LCA's.

1.2 Research Objectives

1.2.1 Primary Objective

The primary research objective of this study is to perform a Life Cycle Analysis of chemical emulsion production in order to identify those parts of the life cycle that are important to the total environmental impact.

1.2.2 Secondary Objective

1.2.2.1 To determine steps of the life cycle which give rise to the most significant environmental input and output flows, i.e. hot spots,

1.2.2.2 To propose improvements and optimise the system

1.3 Rational for the Study

This study was commissioned for internal company evaluation. The objective was to perform a Life Cycle Analysis of chemical emulsion production in order to identify those parts of the life cycle that are important to the total environmental impact. This included the identification of "hot-spots". This meant identifying phases of the life cycle that give rise to the most significant impacts so that the company will be able to propose improvements to the system based on the identified "hot-spots".

Two different emulsion processes are modelled: the Aquapel process and Hi-phase/composite process. The Aquapel product is used in the paper making industry and the Hi-phase/composite process (two scenarios: one based on using a solid rosin feed, the other based on using a liquid rosin feed) product used in the cardboard box industry.

1.4 The Processes

1.4.1 Aquapel (process 1)

The manufacturing of the Aquapel product follows a standard process of mixing, processing and storage. Materials used in the production include wax, starch, water and steam. The final product is used in the paper making industry as a paper sizing agent.

1.4.2 Hiphase/Composite Rosin (Solid – process 2 and Liquid – process 3)

The process is similar to the Aquapel process, except the raw materials, quantities and temperatures vary. The manufacturing of the Hiphase/Composite product using solid and liquid rosin, follows a standard process of mixing, processing and storage. Materials used in the production include chemicals, starch, water and steam. The final product is used for the cardboard box making industry as a sizing agent.

1.5 Potential Outcomes of the Study

The study aims to achieve a clear and distinct indication of:

- the environmental impacts of the three emulsion processes and which of the three emulsion processes has the greatest environmental impact
- the hot spots for each of the processes.

The results generated by this study would contribute to the company and the environment as a whole in the following manner:

- The process(es) that may have the largest negative environmental impact would be refined to ensure that the impacts identified are significantly reduced or eliminated completely. Thus ensuring that the company complies with environmental legislation and making the working environment a safer and healthier place.

- The negative environmental impact would also stimulate discussion regarding usage of alternative cleaner raw materials with less or minimal negative environmental impacts.

- The hot spot identification would enable the company to focus on these problems areas first, thereby increasing process efficiency, decreasing unnecessary shut downs and damage to equipment. Also, ensuring that the quality and quantity of product obtained is of a higher grade.

- Improvement over time of the entire emulsion processes would be initiated.

All of the interventions would also have the effect of:

- Minimizing cost
- Increasing productivity
- Heightened environmental awareness and
- A need to save.

Thus, translating into benefits, such as, increased profits and environmental recognition for the company.

1.6 Addition to Knowledge Base

No study has been performed specifically on these particular emulsion processes. Thus the analysis and results of the use of solid and liquid rosin would be very specific. Thereby, filling a gap in the current knowledge base i.e. data, behaviour, localised and global effects of rosin usage.

1.7 Limitations of the Study

The findings of this study are not necessarily definitive and prescriptive in any way or form as there are many uncertainties and gaps in the study related to data and the methods used. This is due in part to there being no process similar to the production of rosin within the many databases searched and used as well as the LCA tool used. Subsequent sections discuss this in detail. The quantity and quality of data and the methods used required modifications and updates and thus the conclusion to this study can be considered as a second order estimate.

LCA information within the literature sources and LCA studies conducted are similar in many respects and theoretical extracts from various sources have been used as cited in the reference section.

1.8 Structure of Report

Chapter 1 provides an introduction to Life Cycle Assessment, the objectives, rational, outcomes and any addition to the current knowledge base.

Chapter 2 is a review of the literature with reference to tool selection, inventory analysis, impact assessment, data analysis and emulsion studies that may/may not have been conducted.

Chapter 3 discusses the LCA framework and methodology and defines life cycle assessment and it's use and applications according to ISO14041 (1998). The four iterative phases of an LCA according to the ISO 14040 (1997) is also expanded upon i.e. Goal and Scope Definition, Inventory Analysis, Impact Assessment and Interpretation.

Chapter 4 is the first of four phases, Goal and Scope Definition.
Here the goal of the LCA is defined precisely and clearly to address the research objectives and enable decisions to be made regarding the method to be used, the type of data collection, etc. The scope of the study is defined and sets the context, thus determining the borders, aspects to be included, products and methods that will be used. This phase includes the following subsections: Goal, Scope, Functional Unit, Reference Flow, System Boundaries, Data Quality.

Each of these subsections are defined and discussed with respect to Chemical emulsions i.e. the Aquapel process and Hi-phase/composite process.

Chapter 5 relates the importance of Inventory Analysis. The core activity of the inventory analysis, data assimilation and collection, forms the basis of the study. Thus, this phase can in many respects be the determining factor of this study in terms of its credibility and accuracy, and is thus the most time consuming phase of all life cycle assessments.

Chapter 6 discusses Impact Assessment. In this chapter Impact assessment methodologies are used to convert the individual data produced in Inventory

analysis (through multiplying factors, potentials or damage factors) into comparable values so that results may be evaluated and interpreted.

Chapter 7 is the final phase, Interpretation of the LCA. Results from Inventory analysis and Impact assessment are analysed relative to Goal and Scope definition. The results are qualified and evaluated as well as limitations stated.

Chapter 8 draws conclusions and makes recommendations emanating from the study.

CHAPTER 2: LITERATURE REVIEW

A first attempt at LCA was possibly in the form of a look at extended product systems which can be traced back to the early 1960's (Curran, 1996). In the 70's, various case studies using LCA approaches featured. The 80's saw an increasing awareness of environmental issues and manufacturers; retailers and consumers were interested in comparing environmental profiles of alternatives. However, the 90s saw a marked LCA emergence as it took off to become a valuable environmental product analysis tool and a standardised methodology was instituted and made formal.

According to Fava et al (1993) three major workshops / discussion groups in 1990 brainstormed policy and technical aspects of product life cycle assessments, bringing to the public's attention the potential value and the limitations of LCA's.

- Firstly, the World Wildlife Fund and the Conservation Foundation (1990) held a forum to identify and discuss policy issues.
- Secondly, the Society of Environmental Toxicology and Chemistry (SETAC) sponsored a workshop to develop a technical framework for life cycle assessment (Fava et al., 1991). Curran (1996) states that this workshop was instrumental in increasing awareness and understanding of the LCA concept and eventually led to the development of their Guidelines for Life Cycle Assessments: A 'Code of Practice' (Consoli et al, 1993).
- Thirdly, a Leuven (Belgium) workshop on practical aspects of conducting LCA's (Leuven, 1990).

The International Organisation of Standards (ISO) technical committee TC207 who developed the Environmental Management System (EMS) standards (ISO 14000 series) developed the LCA standards, with the first publication of the ISO 14040 series in 1997 and the most recent publication in 2006, which included the following standards:

ISO 14040: 1997	Environmental Management - Life Cycle Assessment- Principles and Framework
ISO 14041: 1998	Environmental Management – life Cycle Assessment Goal and Scope Definition and Inventory Analysis
ISO 14042:2000	Environmental Management –Life Cycle Assessment – Life Cycle Impact Assessment
ISO 14043:2000	Environmental Management – Life Cycle Assessment Life Cycle Interpretation
ISO 14044:2003	Environmental Management – Life Cycle Assessment Requirements and Guidelines
ISO/TR 14049: 2000	Environmental Management – Life Cycle Assessment- Application examples of ISO 14041 to goal and scope definition and inventory analysis.
ISO/TR 14047: 2003	Environmental Management – Life Cycle Impact Assessment- Application examples of ISO 14042.

Many authors are of the opinion that LCA methodology is under development and there is a lack of standardisation (Finnveden, 2000 and ISO 14040: 1997). The level of standardisation of the ISO life cycle assessment standards is more generalised, providing broadly defined steps to follow in a wide variety of industries.

2.1 Environmental Tool Selection

Before any analysis of a process or product is undertaken, the most appropriate and effective tool that would address the goal of the study and communicate the results at a suitable level must be selected. To assess the overall environmental impact of products, such as Aquapel, Hiphase/compoaite liquid and solid rosin emulsions, it is self evident that all processes upstream and downstream of the product life must be considered. Thus, the tool to do this must be some form of a life cycle assessment, whether it follows the ISO methodology or some other approach.

Other tools that address life cycle issues are Design for Environment (DfE) and Life Cycle Costing. DfE (also termed "Ecodesign" and "Life Cycle design") is the systematic integration of environmental considerations into product and process design (National Research Council Canada, 2002) with factors that are more common in product development, such as product performance, cost, cultural and legal requirements (Curran, 1996). DfE utilises (Comparini and Cagan, 1998) at least life cycle thinking within its execution to make and implement decisions to improve the environmental profile of a product and its related function. Life Cycle Costing also related to "total cost assessment" and "full cost accounting" is another tool that employs a life cycle approach. However, this tool only addresses the monetary issues throughout the life of a product, to expose hidden and indirect costs by allocating monetary values to environmental effects brought about by the process or product of concern (Sevitz, 2003).

Therefore LCA is the most appropriate and effective tool for assessing the overall impact of a process or product. For this study the ISO 14040 series LCA environmental tool will be applied.

2.2 Inventory Analysis: Software and Databases

There are numerous software packages that have been developed specifically for LCA. These include SimaPro, TEAM, ECOBILAN and GABI. The package of choice for this study is the SimaPro software package, one that is widely and credibly known. SimaPro is invaluable as it includes several international databases that can be used and modified in any study. These include BUWAL 250 (1998); DK Input Output Database (1999); ETH-ESU (1996); Franklin Associates (1998); IDEMAT (2001); Industry Data 2.0; USA Input Output Database (1998); Methods. Thus an added advantage of SimaPro is that it incorporates all of these databases.

2.3 Impact Assessment Methodology

When the very first LCA was performed in 1969, according to Curran (1996), it was realised that an impact assessment is very necessary to convert data into more understandable and meaningful terms. This initial test was subjective in nature and was later disregarded. Even today there is still no widely accepted methodology that has been developed. In Europe, impact assessment methodology has been driven by the desire of public policy advocates to obtain a single numerical score so that results can be readily understood and interpreted. This has given rise to a large number of proposed methodologies in the last decade (Sevitz, 2003).

Two documents that provide excellent background material on impact assessment methodology in the United States and Europe include (Curran, 1996):

- A Conceptual Framework for Life Cycle Impact Assessment (Consoli et al., 1993) by SETAC, which outlines more of the conceptual approaches and
- Life-Cycle Impact Assessment (EPA, 1994) by the Environmental Protection Agency that summarises 36 potential methods for performing the characterisation and interpretation steps of the methodology.

Although these methodologies were not used in this study, SimaPro, the software package used in this study included several credible and accepted international methodologies.

As per ISO 14040 (1997) and ISO 14042 (2000), there is no scientific basis for reducing LCA results to a single overall score or number, since trade-offs and complexities exist for the systems analysed at different stages of their life cycle.

ISO14042 (2000) argues for the exclusion of this step when comparative assertions are disclosed to the public, and to rather employ a sufficiently

comprehensive set of category indicators. The comparison will then be conducted category indicator by category indicator (Sevitz, 2003).

Overview of Impact Assessment Methodologies

This overview is an extract of Brent (2002) and Sevitz (2003), except the Impact method.

CML from the University of Leiden (Netherlands)

The methodology of the Centre for Environmental Studies (CML) of the University of Leiden was originally published in 1992 (Guinea et al., 2001). This formed the basis of development of the majority of impact assessment procedures, including the Society of Environmental Toxicology and Chemistry (SETAC) LCA code of practice established in 1993, (Consoli et al., 1993). The methodology was updated in 2001 (Guinee et al., 2001) and is the most recent of all the impact assessment procedures. It is compatible with the ISO standard (ISO14042, 1998) and indicates explicitly where it goes beyond the ISO standard.

The classified impact categories for the characterisation step of the procedure are based on up-to-date scientific principles. This was developed within the scientific community of SETAC and its working groups.

The method attempts to be unambiguous in terms of these categories, which are shown in Table 2.1.

Table 2.1 Characteristics of the CML Impact Assessment methodology

Impact categories	**Units of measurement**	**Normalisation and weighting**
Eutrophication	kg of PO_4^{3-} equivalence of substances	Normalisation Choice of normalised values given for: World population (1990) The Netherlands (1997) Western Europe (1995) Weighting No weighting procedure included or recommended
Ozone depletion	kg of CFC-11 equivalence of substances	
Eco- toxicity	kg of 1, 4 dichlorobenzene equivalence	
Green house gases	kg of CO_2 equivalence of substances	
Acidification	kg of SO_2 equivalence of substances	
Photo-oxidant-formation	kg of C_2H_4equivalence of substances	
Human toxicity	kg of 1, 4-dichlorobenzene equivalence	
Energy use	MJ or kg of fuel per MJ kg of waste	
Solid waste biotic resource	kg of Sb equivalence	
Depletion		
Land use	$m^2.yr$ (increase of land competition)	

Ecopoints from BUWAL (Switzerland)

The Ecopoints or ecofactor methodology (Braunschweig et al., 1998) was originally developed in 1990 and updated in 1997 by the Swiss Bundesamt for Umwelt, Wald und Landschaft (BUWAL). It is based on the ratio of actual pollution and resource (energy) use in Switzerland to critical targets that are derived for Swiss policy. The method is also referred to as the 'distance to target method'. The impact categories considered by BUWAL for characterisation, are shown in Table 2.2.

Table 2.2 Characteristics of the Ecopoints Life Cycle Impact Assessment methodology

Characterisation	**Units of measurement**	**Normalisation and weighting**
NO_x	g of equivalent NOx	Normalisation
SO_x	g of equivalent SO_2	The target /critical inventory (mass or energy) for each impact category for Switzerland over one year
NMVOC	g of each NMVOC substance	
NH_3	g of NH_3	
PM10 dust	g of dust less than 10 μm	
CO_2	equivalent g of CO_2 for each substance	
Ozone depletion	equivalent g of CFC-11 for each substance	
Metals into air; Pb, Cd, Zn, Hg	g of metals Pb, Cd, Zn, Hg	The target/critical inventory refers to the aimed level set by the Swiss authorities.
Metals into water; Cr, Zn, Cu, Cd, Hg, Pb, Ni	g of metals Cr, Zn, Cu, Cd, Hg, Pb, Ni	
Metals into soil	equivalent g of Cd for each metal	
COD	equivalent g of COD into water	
P	equivalent of P into water	Weighting
N into Water	equivalent of N into water	Calculated as the ratio of actual inventory value for each impact category.
AOX	g of Cl into water	
Nitrate	g of NO_3 into soil	
Pesticides	g of each pesticide into soil	
Waste	g of each waste type into soil	
Radioactive waste	cm^3 of each radioactive waste type	
Energy use	MJ or kg of fuel per MJ	

The Swiss policy that determines the target values of the emission impact categories is based on scientifically published modelling, which considers the fate of the emitted substances to the final mediums of air, topsoil and surface water.

Eco-indicator 95 from Pré consultants the Netherlands

Eco-indicator 95 method was developed under the auspices of the National Reuse of Waste Research Programme, (NOH), in the Netherlands (Goedkoop, 1996). Similar to the Swiss Ecopoints method, Eco-indicator 95 uses the distance-

to-target methodology with certain modifications. As opposed to Ecopoints, the Dutch method considers the effects of impacts, rather than the impacts themselves during characterisation. Environmental effects are taken as those effects that cause damage to human health and ecosystems on a European scale, Appendix 21.

The impact categories considered by this methodology are shown in Table 2.3.

Table 2.3 Characteristics of the Eco-indicator 95 impact assessment methodology

Characterisation	Units of measurement	Normalisation and weighting
Greenhouse gases	kg CO_2	Normalisation
Ozone layer	kg CFC-11	Normalisation is based on 1990 effects levels for Europe excluding the former USSR
Acidification	kg SO_2	
Eutrophication	kg PO_4	
Heavy metals	kg Pb	
Carcinogens	kg B(a)P	Weighting
Winter smog	kg SPM	
Summer smog	kg C_2H_4	Calculated as the ratio of actual inventory value for each effect category, with additional subjective weighting to represent significance.
Pesticides	kg act.s	
Energy	kg LHV	
Solid waste	kg	

As is shown in Table 2.3, energy and solid waste has been added later as effects on ecosystems in terms of energy resource usage and space requirement for waste disposal. Whereas Ecopoints uses target values for normalisation, Eco-indicator 95 uses the extent of the evaluated effects in Europe – i.e. the current contribution of an effect level. This is also consistent with SETAC LCA guidelines (Consoli et al., 1993), which recommends that current values should be used as a basis for the calculation of normalisation factors. Apart from the distance–to-target weighting factors (i.e. the ratio of current effects to target values for the effects) Eco-indicator 95 also introduces an additional subjective weighting factor to represent the significance of the effects.

Eco-indicator 99 from Pré Consultants (Netherlands)

The Eco-indicator 99 project was commissioned by the Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) in order to update the Eco-indicator 95 methodology. This update compared to the previous version, lie in the characterisation and weighting steps. The effects are allocated three endpoint categories – human health, ecosystem quality and resources, with units of measurement directly indicating the damages to these endpoints, as are shown in Table 2.4 (Goedkoop and Spriensma, 1999).

Table 2.4 Impact Categories (Goedkoop and Spriensma, 1999)

Impact Categories	Units of measurement	Normalisation and weighting
Human health Carcinogenic emissions Respiratory organics Respiratory inorganics Climate change Radiation Ozone layer depletion	Daly's of substances in sub-categories A DALY (Disability Adjusted Life Years) is calculated for each emission into air, water and soil in these subcategories. Links health effect to the number of years lived disabled and years of life lost.	Normalisation Total inventory of mass and energy used (mostly for 1993 as base year) for the whole of western Europe for one year per person (population of 495 million assumed).
Ecosystem quality Eco- toxicity Acidification/Eutrophication Land use	Potentially Disappeared Fraction (PDF) of substances/cause in sub-categories Links effects to Potentially Disappeared Fraction (PDF) for plants.	Weighting A choice of three based on responses from a panel of experts placed into three perspectives: Individuals (higher weight to human health) Egalitarians (higher weight to ecosystem quality) Heraclites (equal weight distribution)
Resources Minerals Fossil fuels	Megajoules (MJ) surplus for each resource Links lower concentration to increased efforts to extract resources in future	

The contributions of effects to the three endpoint categories are the result of extensive modelling to connect damages to life cycle inventory results. Human health modelling is expressed in the Disability Adjusted Life Years (DALY's) scale, which was developed for the World Health Organisation (WHO) and the

World Bank (Murray and Lopez, 1996), and consists of the following steps (Goedkoop and Spriensma, 1999):

Fate analysis: linking an emission to a temporary change in ambient concentration
Exposure analysis: linking the ambient concentration to the dose intake
Effect analysis: linking the dose to a number of health effects
Damage analysis: linking health effects to Daly's

Ecosystem quality modelling is expressed as a Percentage Disappeared Fraction (PDF) of species in a certain area due to an environmental load, the modelling procedure is not homogeneous as with human health and the three effects that are allocated to this damage endpoint are treated separately (Goedkoop and Spriensma, 1999).

Eco-toxicity is expressed as a Percentage Affected Fraction (PAF) of certain terrestrial and aquatic species under toxic stress. A conversion factor is proposed to translate toxic stress to observable damage. Acidification and eutrophication are combined. The observable disappearance of vascular plants in the Netherlands is used as the basis for the modelling.

Land-use and land transformation is based on the empirical data for the occurrence of vascular plants in the Netherlands as a function of the land use type and the area size. Local and regional damages to ecosystems are taken into account in the modelling.

The resource damage category is expressed in surplus energy. This is the expected increase in energy required per kilogram of extracted material. This after a period when the amount of material that has been extracted is equal to five times the cumulative extracted material. The chosen figure of five is subjective and the absolute value of the surplus of the energy has little meaning.

Similar to the previous methodology, normalisation factors are determined at a European scale. Normalisation is executed directly on the effects categories relating to the damage endpoint – categories of human health, ecosystem quality and resources, which the ISO 14042 standard recommends (ISO14042, 2000).

The weighting procedure follows a panel procedure amongst a Swiss LCA interest group. They were requested to rank the three endpoint- categories in order of importance. The response from the panel has been discriminated as adhering to three cultural perspectives:

Egalitarian: with a long perspective, where a minimum of scientific proof justifies the inclusion of an effect.
Individualist: with a short term perspective, where only proven effects are included.
Hierachist: with a balanced time perspective, where consensus amongst scientists determines the inclusion of effects.

Impact 2002+
Life cycle impact assessment (LCIA) methods aim to connect each LCI result (emission or resource use) to the corresponding environmental impacts. Thus, the large number of inventory results, are condensed into a smaller, manageable number of impacts. According to the ISO standard 14044 LCI results are classified into impact categories, each with a category indicator, where the category indicator can be located at any point between the LCI results and the category endpoints (where the environmental effect occurs) in the cause-effect chain. Two main schools of LCIA methods have developed:

- Classical impact assessment methods which restrict quantitative modelling to relatively early on in the cause-effect chain and group LCI results in so-called midpoint categories, according to themes. Themes are common mechanisms (e.g. climate change) or commonly accepted grouping (e.g. ecotoxicity).

- Damage oriented methods which try to model the cause-effect chain up to the endpoint, or damage, sometimes with high uncertainties.

Recently, the definition study of the SETAC/UNEP Life Cycle Initiative (a consensus-building group of global LCA experts) suggested utilizing the advantages of both approaches by grouping similar category endpoints into a structured set of damage categories. In addition, the concept also works with midpoint categories, each midpoint category relating to one or several damage categories. The recently developed IMPACT 2002+ LCIA methodology attempts to put this into practice, and proposes a feasible implementation of the aforementioned combined midpoint/damage-oriented approach.

Figure 2.1 shows the overall scheme of the IMPACT 2002+ framework, linking all types of LCI results via 14 midpoint categories to four damage categories. An arrow symbolizes that a relevant impact pathway is known or assumed to exist. Uncertain impact pathways between midpoint and damage levels that are not modelled quantitatively are represented by dotted arrows. The IMPACT 2002+ method can be used on either level (midpoints or damages) and thus represents an elegant combination of the two approaches. It is therefore chosen for use in this study.

The damage factors used by the IMPACT 2002+ method to aggregate the midpoint impacts into damages are given in Table 2.5. These give an indication of the relative importance attached to the human toxicity and ecosystem quality impacts in terms of actual environmental damage they cause.

The IMPACT 2002+ method supports normalisation at either the midpoint or the damage level. The idea of normalisation is to analyse the respective share of each impact to the overall damage by applying normalisation factors to midpoint or damage impact categories in order to facilitate interpretation. The normalised factor is determined by the ratio of the impact per unit of emission divided by the total impact of all substances of the specific category for which characterisation

factors exist, per person per year. The unit of all normalised midpoint/damage factors is therefore [pers.year/unit$_{emission}$], i.e. the number of equivalent persons affected during one year per unit of emission. The normalisation factors of IMPACT 2002+ are calculated for the population of Western Europe, so are less relevant to South Africa. However, they are still useful to give some indication of the relative magnitude of the impacts, but less emphasis is placed on this in the interpretation of the results of this study. The damage categories are not normalised in the results presented.

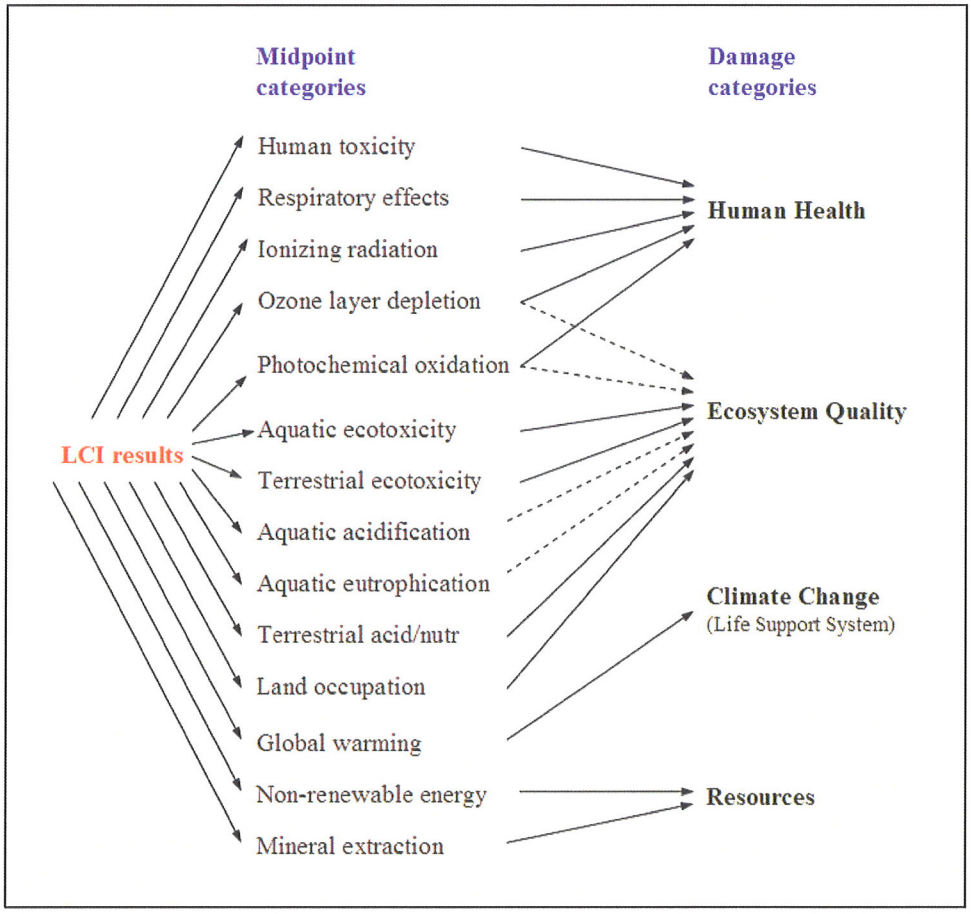

Figure 2.1: Overall scheme of the IMPACT 2002+ framework, linking LCI results via the midpoint categories to damage categories.

Table 2.5 Damage factors used to aggregate the IMPACT 2002+ impact categories into damages.

Impact Category	Damage factor	Units
HUMAN HEALTH (DALY)		
Carcinogens	2.80E-06	DALY / kg C2H3Cl
Non-Carcinogens	2.80E-06	DALY / kg C2H3Cl
Respiratory inorganics	7.00E-04	DALY / kg PM2.5
Ionizing radiation	2.10E-10	DALY / Bq C-14
Ozone layer depletion	1.05E-03	DALY / kg CFC-11
Respiratory organics	2.13E-06	DALY / kg ethylene
ECOSYSTEM QUALITY (PDF*m2*yr)		
Aquatic ecotoxicity	5.02E-05	PDF*m2*yr / kg TEG water
Terrestrial ecotoxicity	7.91E-03	PDF*m2*yr / kg TEG soil
Terrestrial acid/nutrification	1.04	PDF*m2*yr / kg SO2
Land occupation	1.09	PDF*m2*yr / m2org.arable
CLIMATE CHANGE (kg CO2)		
Global warming	1	kg CO2 / kg CO2
RESOURCES (MJ primary)		
Non-renewable energy	1	MJ primary / MJ primary
Mineral extraction	1	MJ primary / MJ surplus

Transparency is critical to this phase, as subjectivity within the impact assessment phase is a highly contentious issue. The choice of categories, damage indicators, modelling and evaluation methods and especially the final weighing of impact categories introduce increased levels of subjectivity (Sevitz, 2003).

No methodologies, publicly available have, as yet, been developed for South African conditions.

2.4 Interpretation

This phase is the most recent and also least elaborated upon development of the four generic phases that the ISO standards have introduced into their LCA series.

In earlier texts, such as SETAC's code of Practice (Consoli et al., 1993), the US guidelines (Vigon et al. 1993) and the Dutch guidelines (Heijungs et al., 1992) there was a final (sometimes optional) phase of process improvement, called the Improvement Analysis.

The Improvement Analysis phase was felt to be an application of LCA and therefore not part of LCA. This difference of opinion and the uncertainty of the LCA results prompted the substitution of improvement analysis with the interpretation phase.

The ISO interpretation standard (ISO14043, 2000) describes several tools of interpretation. These can be classed into (Sevitz, 2003):

- Procedural approaches (including judgements, reports on similar products, reputation of suppliers) and
- Numerical approaches (such as contribution analyses and uncertainty analyses).

Heijungs and Kleijn (2001) describe in detail, the value and technique of five specific numerical approaches, whereas ISO briefly describes three interpretive checks or analyses.

2.5 Data availability, Data uncertainty and General Data Gaps

The Life Cycle Assessment tool is relatively new. Due to the nature of it being resource intensive in the collection of data, the availability and accessibility of data is very often limited. There are no complete sets of South African data bases – only isolated data sets for the limited amount of case studies that have been conducted (Sevitz, 2003). The only data pertaining to this study was data for electricity, transport data for city and long distance driving, and some raw materials data.

The limited South African databases have been based on and adapted from European studies. All other data or foreign data was integrated where serious data gaps occurred.

2.6 General methods of dealing with data uncertainty

As per Chalmers (1982) statistical approaches are generally accepted and favoured by many LCA experts, in the case where a product's claim of environmental preference can be expressed as a probability. Finnveden (2000) agrees on the advantage and use of statistics. He further states that it only partly solves the problem, as some of the uncertainties involve aspects such as reliability of theories and information and ethical considerations. Data gaps, errors, omissions, choices, impact assessment methods and calculation procedures of the inventory analysis as well as technical uncertainties and issues relating to the scientific understanding of processes can be described only inadequately or not at all in a statistical analysis. (Finnveden, 2000)

Reynolds et al. (2000a, b) developed the Relative Mass-Energy-Economics (RMEE) Method which is a systematic statistical approach to objectively exclude unimportant processes without examining the entire system. It is practical, repeatable and quantitative which are highly important attributes of any credible LCA.

Where studies have high uncertainties and are difficult to measure and integrate into the conclusions, a number of general guidelines and rules of thumb based on the experience of LCA experts may be used.

Two rules of thumb based on experience and not supported by quantitative data listed in the Nordic Guidelines on LCA (Lindfors et al. 1995b) that may be used in the absence of other data or information include:

- Emissions of less than one order of magnitude difference should not be regarded as significantly different, and

- Energy and raw materials of less than 50% difference should not be regarded as significantly different.

Finnveden et al, (1996) compared specific parameter variation (such as electricity, SOx, NOx, metals, etc) based on data from independent studies. Finnveden and Lindfors (1998) describe rules of thumb for expected variations in specific types of data. An extract of the data showed differences of up to 3 orders of magnitude apart, although large variations could be explained by mistakes. Therefore the rules of thumb for the expected variations in specific data types were proposed.

For a preliminary study of products broader rules of thumb should be used where the choice of data sets will not result in significant differences in the overall result, despite significant differences in individual data parameters (Sevitz, 2003). In the analysis by Kennedy et al (1996 and 1997) it is assumed that data with low quality will result in a range of approximately 50%. Goedkoop and Spriensma (1999) refer to the Eco-indicator 99 manual for designers where provisional and general guidelines are suggested for dealing with data uncertainties. If the highest contribution processes are considered to be similar the difference between the single scores should be 10 to 50% between the products for a reliable conclusion.

Uncertainties from data errors or flaws or analysis models for similar processes will then be correlated and therefore will tend to compensate each other (Sevitz, 2003). For dissimilar or completely different processes a 100% difference in results is required before reliable conclusions can be drawn.

2.7 LCA studies in South Africa

The status of LCA in South Africa presented below is an extract from Brent A C, von Blottnitz H, et al, 2002.

2.7.1 Legislation

"Development of legislation relating to sustainability, in its broadest sense, follows global trends (Sampson I, 2002). This relates specifically to water and waste, with the Water Act and National environmental Management Act being put forward as very progressive. However, the Atmospheric Pollution Prevention Act of 1965 on the other hand lags behind. Legislative amendments and the ongoing "greening drive" has prompted the recognition of LCA as a useful environmental management tool within the South African manufacturing sector.
Additionally, LCA within the broader manufacturing sectors has taken a turn for the better (Brent A C, von Blottnitz H, et al, 2002)".

2.7.2 Applications of LCA

"Environmental management and LCA in South Africa seems to be more project/project site oriented with LCA being limited to a few Industrial and Academic organisations. This can be attributed to the lack of incentive, however the South African government has done a study to ascertain if an environmental labelling scheme would be of any benefit to South Africa (FRIDGE, 2001). Due to no pressure from government most of the LCA's are voluntarily performed either for internal benefit or academic purposes. As South African exports increase there may be an increased demand for LCA's to be performed by industries.

Many of the industrial LCA's relate to waste minimisation, environmental impact assessment and environmental reporting. Thus, LCA's being used as a tool to determine the environmental burdens and to support the ISO14001 management systems. Other LCA research and application in South Africa has tended towards "consequential modelling" with applications in decision support (Notten P, 2002) as well as design for environment (von Blottnitz H, Petrie JG, 1995).
Some LCA applications as per literature include, generation of environmental profiles, product improvement, ecolabelling, organisation marketing and packing systems (Brent A C, von Blottnitz H, et al, 2002)".

2.7.3 LCA in Academia

"Academia and related institutes have engaged in LCA studies for some time now in response to needs in the resource and water management industries. The resultant being graduates skilled in the use and application of LCA and articles published in local and international journals. Cape Town, Natal, Pretoria and Witwatersrand Universities as well as CSIR have been fore runners in the progressive development of LCA in South Africa (Brent A C, 2002)".

2.7.4 LCA in Industries

"Certain sectors of the South African industry have participated in LCA for primarily internal benefit with little to no incentive to publish their findings. A secondary reason being due to ISO 14000 environmental management improvement strategies and their participation in responsible care efforts of the Chemical and Allied Industries Association (CAIA, 2000).

However, there is no formal agreement on the LCA procedures for South Africa to date and how this information could be disseminated (Brent A C, 2002)".

2.7.5 LCA in Government

"Although limited the South African government in 2002 had a three fold participation in LCA:

- Department of Environmental Affairs and Tourism (DEAT) made reference to LCA as a tool in the Integrated pollution and waste management white paper (DEAT, 2000).

- Water Research Commission, an organisation that reports to the Department of Water Affairs and Forestry (DWAF) is financing and supporting LCA studies.

- The Department of Trade and Industry (DTI) in 2001 used the LCA approach to assess the criteria for eco-labelling (FRIDGE, 2001).

ISO 14040 and 14041 were approved in 1998 and 1999 as South African standard codes of practice with the environmental management framework".

2.7.6 The Future of LCA in South Africa

"South African LCA practitioners, such as von Blottnitz H, Brent A.C, Petrie JG, Sevitz, Notten P and many others who are known both locally and internationally for their progressive LCA stance expect an increase in number of LCA studies. With the ALCANET network methodologies, impact assessments and inventory for the South African market will be developed over time. In addition, external demand for life cycle inventory will further encourage the use of LCA.

Tertiary institutions are currently expanding the number of courses and research in the LCA field to cater for an increased demand for these skills. Research initially focussed on processing industries and waste streams have adapted to evolutionary times have begun to widen the scope of LCA studies throughout the manufacturing sectors. Finally, environmental factors will force the South African market to expand the application of LCA (Brent A.C., Von Blottnitz H, et al, 2002)".

2.8 Emulsion studies using LCA

No studies were found on any of the databases and literature references regarding any kind of study that may have been done on these particular types of emulsions.

The LCA relies on data of the emulsion production process provided by the company and the European and other databases in Simapro itself. Some basic system modelling on rosin production was also required where no LCI data were available and this is based on simple desk-based research.

CHAPTER 3: LCA FRAMEWORK AND METHODOLOGY

3.1 Definition of Life Cycle Assessment

The principle of LCA's was discussed in the introduction, but it is very important to precisely define what is meant by LCA. Lindfors et al, (1995) puts forward a modified formal definition of SETAC regarding LCA:

"A process to evaluate the environmental burdens associated with a product system or activity by identifying and quantitatively describing the energy and raw materials used, wastes released into the environment and to assess the impacts of those energy and material uses and releases to the environment. The assessment includes the entire life cycle of the product or activity, encompassing, extracting and processing raw material; manufacturing; distribution; use; re-use; maintenance; recycling and final disposal, and all transportation involved. LCA addresses environmental impacts of the system under study in the areas of ecological systems, human health and resource depletion. It does not address economic or social effects."

The term "Life Cycle Assessment" is used synonymously with terms like "Life Cycle Analysis", "Life Cycle Approach" and the "Cradle to Grave Analysis".

3.2 LCA Applications

According to the ISO 14041 (1998), illustrated by Figure 1.2, the major applications are achieved by conducting comparative LCA's between two or more products that fulfil the same function or 'hot-spot' identification. The major phases of environmental concern in the life cycle of the process or product will be identified for possible product development and improvement.

Conclusions drawn from an LCA should be integrated into a wider framework together with other decision support tools. LCA are not standalone decision making tools and do not result in action being taken. They are informative tools,

used by management and decision-makers to decide on the appropriate choices and decisions.

3.3 ISO LCA Phases

According to the ISO 14040 (1997), an LCA is divided into four iterative phases. These Phases are:

Chapter 4: Goal and Scope Definition
Chapter 5: Inventory Analysis
Chapter 6: Impact Assessment
Chapter 7: Interpretation

The phases are introduced here, however further elucidation of these phases will occur in the chapters that follow.

3.3.1 Goal and Scope Definition

In this phase the objective of the study is described. This includes the intended application and audience and the reasons for carrying out the study. The scope of the study defines the limitations of the study; the functions of the systems investigated; the functional unit; the system boundaries; the allocation approaches; the data requirements and data quality requirements; key assumptions; the impact assessment methodologies used; and interpretation methods and techniques.

3.3.2 Inventory Analysis

The inventory analysis primarily involves the collection of data and calculation procedures to quantify the inputs and outputs of the product system to include all relevant resources and energy use and environmental releases associated with the product life cycle within the defined system boundaries. Figure 1.1 illustrates the systems that form part of a product's life that are analysed in an LCA.

Performing an LCA is an intensive process; thus practical constraints must be considered and reported on. It is important to understand and take note of the fact that availability of good data is crucial to any successful study (Sevitz, 2003).

3.3.3 Impact Assessment

In this phase the significance of potential environmental impacts is evaluated using the results from the inventory analysis.

There are four mandatory elements described by ISO 14042 (2000):

- Selection of impact categories (e.g. climate change, global warming, ozone depletion etc.) , or category indicators and models
- Assignment of the inventory results to selected impact categories (classification)
- Calculation of category indicator results (characterisation) where each data type is multiplied by a comparative damage factor (e.g. global warming potentials)
- Data quality analysis

The following elements are optional:

- Normalisation: calculating the magnitude of category indicator results relative to a reference value-such as total CO_2 emission
- Grouping: into more highly aggregated categories such as human health, Eco-system impacts and damage to resources
- Weighting: in order to obtain a final single score to reflect the total impact

Impact Assessment Framework

The ISO 14042 (2000) forms the basis for the framework for these methodologies. ISO describes two mandatory elements; *Classification* and *Characterisation* used in the conversion of the inventory results to indicator results. In addition, there are three optional elements, *Normalisation, Grouping or Weighting* of the indicator results, Sevitz (2003).

Mandatory Elements

Classification

All substances are sorted into classes, i.e. human health, ecosystem quality, climate change and resources, depending on the impact and effect they have on the environment. These classes are referred to as impact/damage categories.

The inventory results may be assigned to one category or to all four depending on their effects, e.g. NO_x is toxic, acidifying and causes eutrophication, therefore falls into 3 categories. If these effects are independent of each other, double counting is permissible, whereas counting of different effects in the same chain, is not permissible.

Characterisation

The substances are aggregated within each class i.e. human health, ecosystem quality, climate change and resources, to produce an impact score with common units. Weightings are then applied and some substances have higher/greater effects than others.

"For example, the global warming category converts emissions into global warming potentials (GWP), expressed as kg CO_2 equivalents. Carbon Dioxide has a GPW of 1, whereas methane has a GWP of 21. The converted results are then aggregated within each impact category. The outcome is a single numerical indicator result for each of the respective categories".

Optional elements

Normalisation

A normalisation step is required to get a better understanding of the effects.
Each effect is benchmarked against a known total effect for each of the classes.
The relative contribution from material production to an existing effect is made possible with normalisation, e.g. the ratio of the impact of emission divided by the total impact of all substances of the specific category for which characterisation factors exist, per person per year.

Grouping

The Impact 2002+ methodology used in this study has four classes - damage to 'human health, ecosystem quality, climate change and resources', with impact categories assigned to one or more sets of a more aggregated nature. Thus sorting and/or ranking, i.e. high, medium, and low priority, may be required and is based on value choices

Weighting

Normalisation greatly enhances our interpretation of the results. But no final conclusion can be drawn as not all effects have the same importance. Here the normalised effect scores are multiplied by a weighting factor. This weighting factor represents the relative importance of the effect.

As weighting is not a natural science, this step can be highly subjective in nature and it is not recommend by ISO14042 (2000) when the results are intended for public comparison. It is preferable that individual impact categories (characterised or normalised) be compared against each other. Weighting is generally for internal company use, for design and comparison purposes.

Chosen Methodology

The main impact assessment methodology used in this study is Impact 2002+. However, other methods are used to ensure consistency in the findings, except CML which has merely been stated and not used. The choices of methods and assumptions used in these methodologies can be found in each of the respective methodologies manual (referenced in their respective sections).

Transparency is critical to this phase, as subjectivity within the impact assessment phase is a highly contentious issue. The choice of categories, damage indicators, modelling and evaluation methods and especially the final weighing of impact categories introduce increased levels of subjectivity (Sevitz, 2003).

3.3.4 Interpretation

This is the final phase of the LCA. The results are analysed relative to Goal and Scope definition, where conclusions are reached, limitations of the results are presented and recommendations are provided based on the findings of the preceding phases of the LCA. Interpretation throughout the other three phases ensures that the study's findings are relevant to the objectives defined in the initial phase (Curran, 1996, Sevitz, 2003).

According to Sevitz (2003) an LCA is generally an iterative process. The impact assessment helps increase the knowledge about what environmental inputs and outputs are important. This knowledge can be used in the collection of better data for those inputs and outputs in order to improve the inventory analysis. The scope, assumptions, data quality descriptions, methodologies and results of the LCA study must be transparent to be effective and credible.

CHAPTER 4: GOAL AND SCOPE DEFINITION

LCA studies are generally performed in response to a specific set of questions. According to Curran (1996), the nature of the questions determines the goal and scope of the study. It is thus important to define the goal of the LCA precisely and clearly to address these questions and enable decisions to be made regarding the method to be used, the type of data collection, etc.

The scope of the study sets the context, thus determining the borders, aspects to be included, products and methods that will be used.

This phase deals with the following subsections:

- Goal
- Scope
- Functional Unit
- Reference Flow
- System Boundaries
- Data Quality

Each of these subsections are defined and discussed with respect to Chemical emulsions i.e. the Aquapel process and Hi-phase/composite process.

4.1 Goal

The primary goal of this study is to compare and analyse the environmental performance of three types of emulsion, Aquapel, hiphase/composite liquid and solid rosin that fulfil a specific function as a sizing agent in the paper making and cardboard box industries respectively. The environmental performance is assessed by the impact they would have on the environment during the production stages. The audience in this case is specifically the company commissioning the study. However, it may also be of interest to the Chemical and Allied Industries Association (CAIA), policy makers and environmentalists.

4.2 Scope

The scope of the study is geographically confined to South Africa. The study relies on data of the emulsion production process provided by the company. Where South African data was lacking, International data was used. This data was used only because it was believed to increase the accuracy of the final results.

4.3 Functional Unit and Reference Flow

Weidema (1993) suggests that for a comparative study, defining equivalent functionality is a critical step for the whole study. The functional unit is the primary basis for this comparative study which relates the quantities of material or products to be compared. The functional unit magnitude sets the scale of the comparison of two products and does not affect the conclusions of the actual comparison. It is thus used as a reference to which all input and output data collected in the inventory phase are normalised.

In this study the functional unit is defined as one ton of emulsion product. Thus, the three emulsion processes are compared per ton of product produced.

The reference flow refers to the flow of emulsion in a batch process system with the Aquapel process emulsion flow producing 5 tons of product and both the Hi phase/composite process emulsion flows, i.e. liquid and solid rosin, producing 10.9 tons of product.

4.4 System Boundaries

The initial system boundary defines the unit processes that are to be included in the system. Ideally, all inputs and outputs should be included. However, this is not practical as there is usually insufficient time, data or other resources to conduct a comprehensive study to include the inputs or outputs of, e.g. the manufacturing of a tyre for a truck that is transporting liquid rosin to the emulsion manufacturer. The effects that processes located on the outer boundaries of the

study have on the final impact of a product become less significant and negligible due to the statistical outlier effect (Consoli, et al, 1993, Sevitz, 2003).

The general rule for excluding steps from the study is that a step may be excluded only if doing so does not change the conclusions of the study (Curran, 1996).

Thus, resources need not be expended on the quantification of minor or negligible inputs and outputs that will not significantly change the overall conclusions of the study (Curran 1996). Decisions must therefore be made regarding which environment will be evaluated. Omissions must be stated and justified.

In addition to determining what processes fall within the LCA boundaries, there are three other types of boundaries that must be considered. These are:

4.4.1 Temporal coverage

Temporal coverage (Sevitz, 2003) is defined as "The desired age of the data, i.e. for example within the last 10 years and the minimum length of time, for example every 2 years".

Thus all decisions based on the results of this study will occur in the future. Therefore, one would assume that data based on future environmental inputs and outputs should ideally be used. However, industry is constantly in a state of flux as its processes and technologies change due to many different reasons and so do the type of inputs and outputs involved in manufacturing the product. The product is a function as described in the functional unit. Extrapolation is the only method by which future changes in data can be obtained. Thus the uncertainties involved in this procedure are large and therefore, the most current data is used to reflect current situations. The company provided data for eight months of the year January to August 2007.

4.4.2 Geographical (or Spatial) coverage

Geographical Coverage (Sevitz, 2003) is defined as "the geographical areas from which data for unit processes should be collected for example local, national, global". The study concerns emulsions manufactured and used in South Africa. Although the collection of data is exclusively South African, it is accepted that data gaps are possible and that the use of available international data and other data sources is necessary. These processes, however, must be similar to the South African processes or the database information would have to be modified to the South African context. Preliminary and process data was obtained from the company commissioning the study.

4.4.3 Technology coverage

Technology Coverage (Sevitz, 2003) is defined as "the type of technology used, for example best available technology, BAT". The study aims at describing typical South African conditions where a medium sized company was studied. Thus the data collated is the result of average machinery, operation and process conditions.

4.5 Allocation Procedure

Tracking and tracing the material and energy flows of the product system is the cornerstone of any Life cycle inventory analysis. It relies on being able to link the various unit processes. In industry there is no linearity of flows that produce a single output, but are based on material and energy flows that are associated with multiple outputs and their associated environmental releases which are allocated to the different products (ISO 14041; 1998).
ISO 14041 (1998) advocates the following stepwise allocation procedure:

- **Step 1**

"Wherever possible, allocation should be avoided by dividing the unit process to be allocated into two or more sub-processes and collecting the

environmental data related to these sub-processes or by expanding the product system to include the additional functions related to the co-products".

- **Step 2**

"Where allocation cannot be avoided, but the amount of the co-products can be independently varied, the allocation should be done in a way which reflects the underlying physical causal relationships between the products and the environmental inputs and outputs of the system".

- **Step 3**

"Where physical causal relationships alone cannot be used as the basis for the allocation, economic or other relationships should be used instead."

4.5.1 Co-Product Allocation

Curran (1996), states that co- product allocation is "the allocation of inputs and outputs of a process to the various co-products being produced". Mass basis is the most common form of co-product allocation that is used. Stoichiometry and heat of reaction are some of the other methods that may be used. Economic value of co-products can also be used as an indicator of the energy levels and resources that are required to produce the product. This is due to it being less resource intensive, such as time and money, in obtaining the economic value of most products. Curran (1996) does not recommend this approach as the inventory is based on the measurement of physical parameters, and economic value is not a physical parameter. Also, the economic value can be skewed. This due to government subsidies of certain industries (such as gold) changing frequently. This change is not based on the energy and resources used in extraction and production of the finished product. Thus a low correlation factor is achieved (Sevitz, 2003).

In this study allocation is based on mass and has been used for all relevant processes. This includes both upstream and downstream processes. The allocation

will include all inputs and outputs and related sub- processes excluding transport, use of product and infrastructure.

4.5.2 Allocation of Recycled Material

The emulsion product contains no recycled content. Thus any waste is assumed to be negligible and thus open or closed loop recycling was not considered.

4.6 Data Quality Requirements

The quality of the final results is a good indication of the quality of data used in the inventory phase. Data quality can be described and assessed in many different ways.

This section deals with the data quality requirements used in this study. The quality aspects described in ISO 14041 (1998) and the data quality that has been obtained in the study are described briefly. Further elucidation of data quality is described in the interpretation phase.

The nature of the data must also be stated. This is described in a qualitative manner, as it is generally difficult to describe the nature of data quantitatively.

It must be stated whether it is primary, secondary or tertiary data, i.e. if the data was measured, calculated or estimated and also if it was collected from published or existing data. The inventory analysis details this. Furthermore, the level of detail required or obtained must be considered. The qualitative description includes the following:

- **Precision**

  "This is a measure of the exactness (or variability) of the data values. The aim is always to obtain as high a precision as possible within the framework of the study. In most case studies, however, the uncertainties in the data are large" (Sevitz, 2003).

The company studied provided data based on their records and on their best experience estimates in the industry over an eight month period. A longer period of data would have been preferable and thus precision will not be very high.

- **Completeness**

  "This is the number or percentage of locations reporting primary data to the study. The concept of completeness can also be used to discuss data gaps in the study. The aim is always to obtain as high completeness as possible within the framework of the study. Most case studies, however, include significant data gaps" (Sevitz, 2003).

  This study included the main chemical emulsion manufacturer and thus completeness would be high, of the order of 85%, with gaps in data being filled by international databases, information relevant to South African conditions, modified international databases and more significantly the Ecoinvent database. However, the data itself was based on production data and staff responses to questions posed. Thus data gaps are likely.

- **Representivety**

  "Qualitative assessment of the degree to which the data set reflects the true population of interest. This is related to and has been explained in the preceding section of system boundaries. Specifically referring to temporal, geographical and technological coverage" (Sevitz, 2003).

- **Consistency**

  "Qualitative assessment of how uniformly the study methodology is applied to the various components of the analysis" (Sevitz, 2003). In this study the system boundaries and allocation procedures are based on the same method and principles respectively. Company specific data was obtained where possible and where possible published data was then used

and integrated into the databases. Significant use of the Ecoinvent database to fill data gaps would thus ensure consistency.

- **Reproducibility**

  "Qualitative assessment of the extent to which information about the methodology and data values allows an independent practitioner to reproduce the results reported in the study" (Sevitz, 2003).

4.7 Impact Assessment Methodologies

Four different impact assessment methodologies were selected to analyse and interpret the inventory and impact assessment results. However, the main method used was Impact 2002+ with the remaining three methods, Ecoindicator 95, Ecoindicator 99 and Ecopoints used to corroborate or dispute the results of the Impact 2000+ method but to also ensure consistency within the study.

4.8 Software Packages

The software programme SimaPro developed by the Dutch LCA consulting company Pré Consultants and the services of a Simapro expert were used in the study. Software packages can be of immense use in speeding up calculations relating to the inventory analysis and impact assessment. SimaPro is widely used and an accepted LCA software package.

CHAPTER 5: INVENTORY ANALYSIS

The core activity of the inventory analysis, data assimilation and collection, forms the basis of the study. Thus, this phase can in many respects be the determining factor of this study in terms of its credibility and accuracy, and is thus the most time consuming phase of all life cycle assessments. High quality data can often only be obtained by on – site measurements, interviews with different employees and detailed investigations into the records of the involved companies throughout the product life cycle (Sevitz, 2003).

According to Weidema (1993) theoretical calculations of the actual production processes can sometimes yield data of a quality, which is old, imprecise and poorly documented. Qualified guessing is also used frequently, at least to fill in gaps and to select and adjust data from different sources. However, data based on qualified guessing is always better than no data (Sevitz, 2003).

The data and methodology used in this report are still under development as a lot of the data is derived from aggregated South African, European and US data and should be seen as a representation of the company or product sector in South Africa. For basic energy and material data sets there are almost no uniquely South African data sets produced or available publicly, thus information from Eskom reports have been used.

5.1 Data collection procedures

For any LCA data availability is a common problem, more especially in South Africa as the consideration of environmental issues in all spheres of industry is a relatively new field.

Initially data was obtained using an the Eco Inspector, an Excel based spreadsheet questionnaire developed by the University of Basel, which reflects the qualitative and to some degree the quantitative nature of data requested, Appendices 15 to 20.

Further detailed data was obtained through site visits and questioning the factory manager, personnel in similar positions and the accountant. Plant visits to acquire information and data was the main method of acquiring data as the plant site was within travelling distance. Any additional basic data needed was obtained via telephone. Although the information and data supplied was confidential, staff were willing to assist at all times and supplied as accurate as possible data or as accurate as the process would allow them.

Data collection limitations included the following:

- Data (some) was considered to be confidential.
- Data was not readily available or accessible. The specific nature of data required was different to what the company normally generates for their business purposes.
- Data was technically difficult to obtain, e.g. steam allocation to different processes.
- System boundaries with the natural environment were not easily defined e.g. inclusion of forestry or not.

Not-with-standing these limitations, the LCA nevertheless produces a reasonable second order approximation. This provides a basis from which to work and indicates subsequent steps to be taken.

The exact source and quality of the data for each unit process is discussed in section 5.2. The data collected in this stage was initially captured into spreadsheets, Appendices 1 to 5, so that the raw data could be converted into a suitable format to be entered into the LCA software programme SimaPro.

5.2 Sources of Data

5.2.1 Aquapel (process 1)

The manufacturing of the Aquapel product, Figure 5.1, follows a standard process of mixing, processing and storage. Materials used in the production include water, starch, and steam. The final product is used in the paper making industry as a paper sizing agent. The assumptions made and the source of the materials is covered in detail in section 5.2.4, the inventory models section.

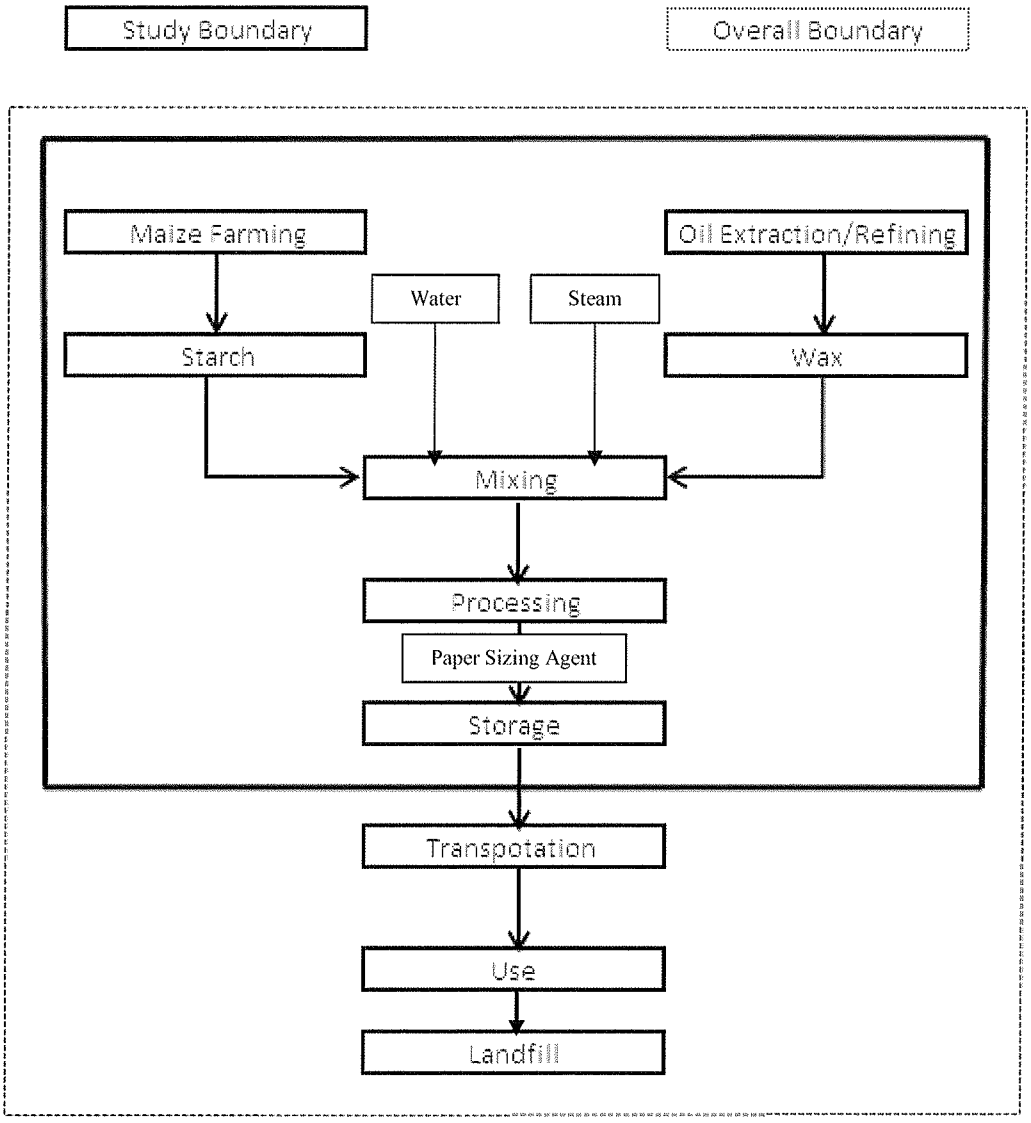

Figure 5.1: Process Flowsheet of the Aquapel Emulsion Plant – Paper Industry

5.2.2 Hi-phase/composite Rosin (Solid – process2 and Liquid – process 3)

The process is similar to the Aquapel process, except the raw materials, quantities and temperatures vary. The manufacturing of the Hi phase/ Composite, solid and liquid rosin product, Figure 5.2, follows a standard process of mixing, processing and storage. Materials used in the production include chemicals water, starch and steam. The final product is used for the cardboard box making industry as a sizing agent. The assumptions made and the source of the materials is covered in detail in section 5.2.4, the inventory models section. The third process differs in that the rosin used is liquid but follows the same process flow.

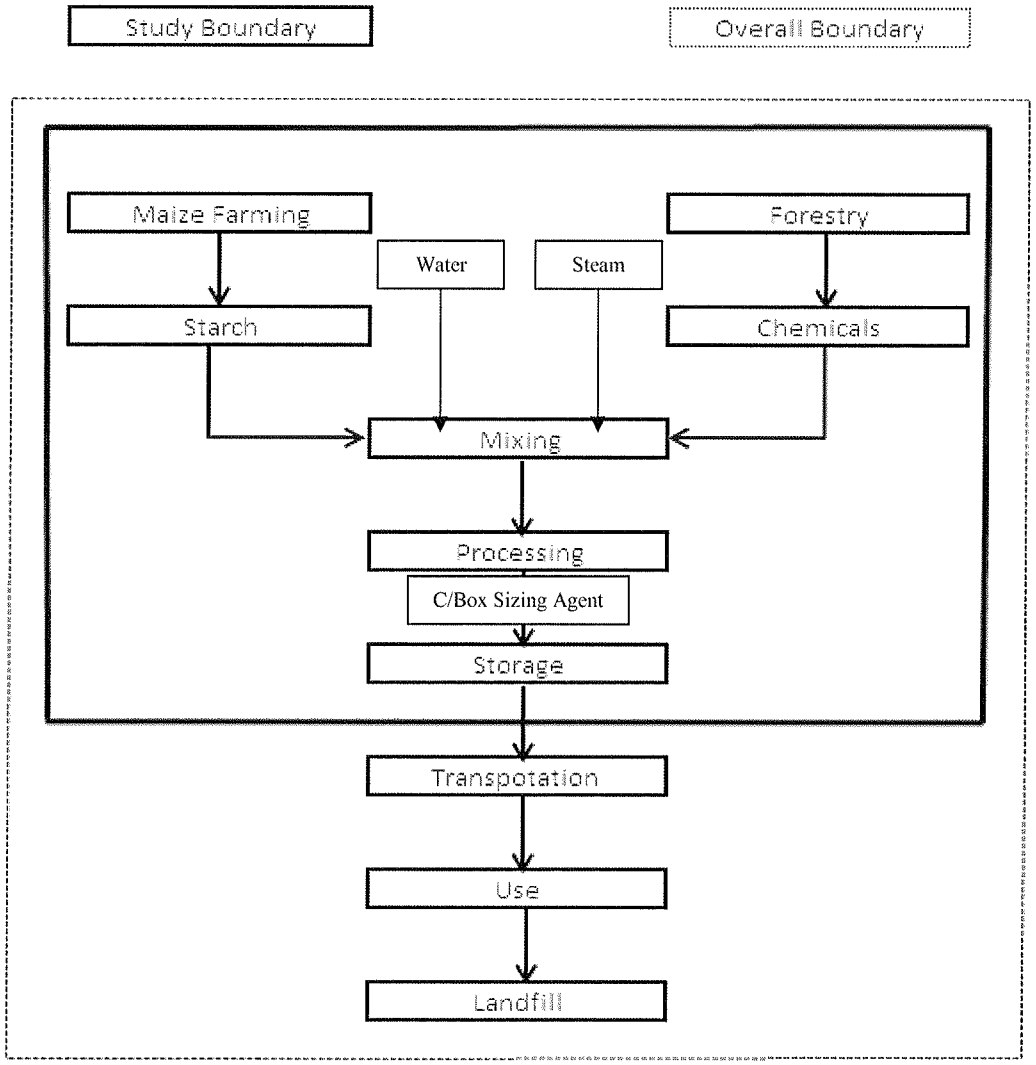

Figure 5.2: Process Flowsheet of the Hi –Phase/ Composite Emulsion Plant – Cardboard Box Industry

5.2.3 General approach to data collection

Only the emulsion production process is modelled with process specific data. Generic Life Cycle Inventory (LCI) data is used for all upstream and downstream processes (i.e. the production of the materials used in the emulsion process and the treatment of the effluent). A challenge for LCA practitioners in South Africa is that the detailed LCI data available in LCA databases are predominantly for Europe. A considerable step forward for non-European LCA practitioners has been the publication of non-aggregated or unit process LCI data. Previously all LCI data was published on a result level, i.e. as resource inputs or final emissions to the environment, whilst unit process data specifies the input materials into a particular unit process, e.g. a "traditional" LCI for a paper mill would present an inventory with resource inputs, e.g. wood, coal, diesel fuel etc., and the emissions associated with the production and use of these materials and fuels summed together with the emissions from the paper mill. A unit process inventory, on the other hand, will specify an input of "wood at saw mill", "heat from coal boiler" and "transport of wood in 32 ton truck". This allows the LCA modeller to input wood and coal from a specific source and boiler efficiency, and to specify local transport data (e.g. to adjust the distance and fuel efficiency of the truck). It is therefore possible to create a "hybrid" inventory with base European data (the material requirements and emissions of the paper mill), but contextualised to South Africa (the wood, coal and transport data).

The ability to change the electricity input in unit process inventories is especially important, as emissions from electricity very often dominate the environmental profile of materials. This is especially important for South Africa, whose very coal-dominated electricity grid mix differs considerably from many European countries, where the much higher shares of gas, hydro, wind and nuclear power result in a significantly different environmental profile.

At present only the Ecoinvent database (Ecoinvent Centre, 2006) is available in unit process format. This database, with more than 2500 datasets, is also the most comprehensive LCA database available. It is therefore chosen to supply base LCA

data where non-factory specific data has been used. Under each data record, changes that were made to the Ecoinvent process records to make them more relevant to South Africa, are documented.

In general, however, the Ecoinvent data is adjusted for:

- The South African electricity grid mix
- Local transport distances and transport modes, fuel efficiency and diesel quality (sulphur content)
- South African coal (i.e. coal from a South African mine using local transport distances) and local coal quality (calorific value, ash and sulphur content)

Adjusting the Ecoinvent process records is a fairly time-consuming process, so only those processes with a significant contribution to the system total (typically those contributing more than 2% to any damage category) are adjusted.

5.2.4 Inventory Models

Emulsion production

Data on the three emulsion processes has been supplied by the commissioning company and is summarised in Table 5.1. Only major process inputs are included, and waste water to municipal drains is the only output considered. The two Hi-phase/composite processes are assumed to be identical in their process requirements, other than their steam requirements (because of the much longer time required to heat the solid rosin than the liquid rosin).

Effluent is calculated from the inputs. It is assumed that 10% of the cooling water make-up is lost to evaporation and the balance is discharged to drains (note: this is a very rough assumption as cooling water is divided between make-up to the closed-loop cooling circuit and cooling water used in a once-through system for piston cooling, but the relative amounts used in these two systems are not known).

Steam condensate is used in cleaning and is assumed to be subsequently discharged down the drain.

Water and electricity data are provided on a monthly basis and thus need to be allocated between the Aquapel and the Hi-phase processes. A simple mass allocation is applied in the absence of any more detailed process knowledge. To arrive at the figures in Table 5.1, the kL (and kWh) consumed in the month are divided by the total mass of products produced during that month, and then multiplied by the mass of product produced per batch (an average value is used by calculating the mean over the 8 months for which data are provided). The monthly water data is assumed to be the total water requirements (process and cooling water combined), so the cooling water use is calculated as the total figure less the process water requirements (i.e. the water that forms part of the product).

Table 5.1: Process and Utility Flows taken into account in Emulsion Production

Process inputs / outputs per batch	**Units**	**Aquapel**	**Hi-phase/composite**	
			liquid rosin	**solid rosin**
Inputs				
Wax/rosin	kg	641	3000	3000
Starch	kg	600	400	400
Steam	MJ	2282	8116	18260
Process water	kL	4.3	7.5	7.5
Cooling water	kL	10600	23100	23100
Electricity	MWh	2.5	5.5	5.5
Outputs				
Product	tons	5	10.9	10.9
Effluent	kL	9500	20800	20800
Steam condensate	kL	0.8	3.0	6.7

The steam usage is approximated. A low and high daily usage is given in tons. To relate this usage to the individual processes, the average hourly usage is estimated by taking the average of the low and high daily values and dividing by 9 (assuming a 9 hour work day). This hourly usage is then multiplied by the duration for which the steam is required by the process, i.e. 2.25 hours for the Aquapel process and 2.5 hours for the Hi-phase/composite process. The additional steam usage required to prepare the rosin for the Hi-phase/composite process is also calculated on a time basis (8 hours to prepare the liquid rosin and 48 hours to prepare the gum rosin). It is these total steam usages, i.e. rosin preparation plus batch time that are given in Table 5.1. There is assumed to be no pre-treatment of the wax input into the Aquapel process. The energy required to raise the steam is calculated using steam tables, assuming saturated steam at 20 bar and that the feed water to the boiler is at 18°C and 1 atm.

Inputs common to both processes

A number of inputs are common to both systems. These are discussed here before providing details on where the processes differ. The data used to model the life cycle burdens of electricity, transport and steam production are discussed separately.

The starch input is assumed to be maize starch (typically the source used in South Africa). Accordingly, its production is modelled using the Ecoinvent inventory "Maize starch, at plant" (adjusted with SA electricity). The starch is assumed to be locally produced (as there is a major supplier in the greater JHB area), and as such is assigned a transport distance of only 200 km.

The process water and cooling water is assumed to be municipal water supply, and as such is modelled with the Ecoinvent inventory "Tap water, at user" (adjusted with SA electricity). All liquid effluent (cooling water leaks, once-through cooling water, cleaning water and excess steam condensate) is assumed to be discharged to the drains. The drains are assumed to be connected to a municipal sewer system, and thus all effluent is assumed to ultimately end up in a

municipal effluent treatment plant. The burden of effluent discharge is therefore modelled with the Ecoinvent inventory "Treatment, sewage, to wastewater treatment, class 1" (adjusted with SA electricity).

The Aquapel process

The wax used in the Aquapel process is assumed to be a paraffin wax (i.e. is derived from crude-oil). This may not be accurate for South Africa where it might also be supplied by SASOL, and therefore be coal-based. However, there is no LCI database that covers the Fischer-Tröpsch process (the process Sasol uses to convert coal and gas to liquid fuels). There is furthermore no inventory on wax in Ecoinvent (or any other database in SimaPro), so the paraffin wax is approximated by the inventory "Paraffin, at plant" (adjusted with SA electricity and SA coal furnace). This is approximate, but at least provides likely material and energy requirements and emissions for a similar process.

The Hi-phase/composite process using solid rosin

No LCI data on rosin production could be found in the SimaPro databases or via a literature search. The Ecoinvent databases has an inventory called "rosin size", but this is merely a combination of soap and sodium hydroxide, and upon closer examination, the soap input is comprised of soya and coconut oils. This inventory therefore does not seem applicable to the gum rosin used in the Hi-phase/composite process. A literature search was therefore conducted and an approximate inventory derived for the production of gum rosin.

The gum rosin is imported from China, where the oleorosin (the raw material from which the gum rosin is produced) is primarily obtained from tapping pine trees in natural forests. Assuming the tapping is done sustainably, the forestry and tapping can therefore be omitted from the inventory. The process by which rosin is produced from natural pine resin is very simple, and basically consists of washing and distilling the natural pine resin. Material inputs into the process include diatomaceous earth (modelled using the Ecoinvent record "Kaolin, at

plant"), oxalic acid (approximated by the Ecoinvent inventory "Chemicals organic, at plant"), and water to wash the resin (assumed to be river water). The steam required for distillation is estimated from the time required for distillation and based on the steam requirements of a similar process. The steam is assumed to be produced in a coal-fired boiler (modelled using the Ecoinvent inventory for a coal-fired furnace adjusted for SA, as China is assumed to be more similar to SA than Europe). The rosin is assumed to be transported 7000 nautical miles in a freight tanker to Durban (modelled using the Ecoinvent inventory "Transport, transoceanic freight ship/OCE") and a further 600 km by truck from Durban to the factory.

The burden of production of the fumaric acid input into the Hi-phase/composite process is approximated by the Ecoinvent inventory "Chemicals organic, at plant". This provides a global average of the burdens from the production of common organic chemicals, and is used in the absence of any other specific information on the chemical. The fumaric acid is assumed to be locally produced, and as such is assigned a transport distance of only 200 km by truck.

The Hi-phase/composite process using liquid rosin

The liquid rosin is locally produced as a by-product of the Kraft process (pulp production). It is therefore modelled using the Ecoinvent inventory for Kraft pulp "Sulphate pulp, ECF bleached, at plant". This inventory is substantially adjusted to make it more relevant for local pulp production by replacing the European electricity input with the SA electricity grid mix and replacing the heavy fuel oil and natural gas inputs with an equivalent use of energy from coal (and a South African coal furnace and coal transport data). However, tall oil is a minor by-product compared to the main output of the Kraft process (pulp) and only a small portion of the total emissions from the pulp process should therefore be allocated to the tall oil (and thus to the liquid rosin produced from the tall oil). Approximately 15-20 kg of tall oil is produced per tonne of air-dried pulp, so basing the allocation on mass, 2% of the burdens from the Kraft process are

allocated to the liquid rosin. The tall oil is assumed to be transported 600 km by truck to the factory.

5.2.5 Electricity

Electricity production is modelled by combining various adjusted Ecoinvent records to represent the South African electricity technology mix. This is done to achieve a balance between the detailed Ecoinvent data, whilst including a high degree of relevance to South Africa.

Using the Eskom production mix for 2006 the South African electricity grid was modelled using the following Ecoinvent inventories:

- Electricity, hard coal, at power plant (89%)
- Electricity, hydropower, at reservoir power plant, non alpine regions (4.6%)
- Electricity, hydropower, at pumped storage power plant (1.2%)
- Electricity, natural gas, at turbine, 10MW (0.3%)
- Electricity, nuclear, at power plant pressure water reactor (4.9%)

The Ecoinvent inventory for pumped storage is adjusted by substituting South African electricity grid mix power for average European power. A number of adjustments were made to the Ecoinvent inventory for coal power:

- The Eskom average thermal efficiency for 2006 is used (34%)
- The De-SOx and De-NOx processes removed, i.e. material inputs for these processes removed from the inventory and the SO_2 and NOx emission values adjusted to Eskom values.
- Cooling water consumption changed to Eskom value (1.4 l/kWh)
- Coal input changed from "supply mix" to "at mine" since vast majority of Eskom stations are mine-mouth (i.e. all coal transport excluded).
- Ecoinvent record for "Hard coal, at mine" used (adjusted with SA electricity mix) for coal input.

- Input coal quantity based on average net calorific value of coal used in Eskom stations (19.58 kg/MJ).
- Emissions to air updated with Eskom emission data for particulates, NOx, SO_2, CO_2 and ash.

Following the Ecoinvent database structure, the inventory for the South African electricity production mix is then used to construct inventories for high voltage, medium voltage and low voltage power (at grid). These inventories describe the transmission of electricity, including electricity losses and direct emissions to air (ozone and N_2O for high voltage, SF_6 for medium and low voltage). Emissions are taken from the Ecoinvent data, whilst line losses are based on the Eskom average losses for 2006 (8.2%). The Eskom data gives only the total losses, so these are split between high, low and medium line losses, thus 7% of transmission losses are attributed to high voltage losses, 13% to medium voltage and 80% to low voltage.

5.2.6 Energy (heat from coal)

All non-electrical process energy is assumed to be supplied by steam raised in a coal-fired furnace. Emissions associated with the energy required to raise this steam are calculated using the Ecoinvent record for coal furnace adjusted with South African coal data to make it more relevant to South Africa. This adjusted inventory for heat from coal is also used to adjust other Ecoinvent production records to change energy source to make it more applicable to South Africa, e.g. the heat input from gas and fuel oil in the Ecoinvent kraft pulp inventory is changed to heat from coal.

Adjustments made to the Ecoinvent inventory for coal furnace ("Hard coal, burned in industrial furnace 1-10MW") include:

- Changing electricity use from Average European to the South African grid mix

- Coal input changed to a representative Middelburg/Witbank washed coal product with CV = 27.4 MJ/kg, ash = 14.7%, C = 70%, S = 0.52%
- Emissions of SO_2, CO_2, particulates and ash adjusted to be coal-dependent (i.e. calculated based on the quality of the coal)
- Ecoinvent record for "Hard coal, at mine" used (adjusted with SA electricity mix) for coal input.
- Coal transport: assumed 200 km road transport in 40 ton truck, with empty return leg)

5.2.7 Transport

Transport of raw materials is assumed to take place in large trucks (40 tons). Trucks are assumed to travel fully loaded one-way, and return empty.

Emissions from the transport steps are based on the inventories for truck transportation from the Ecoinvent database, which are adjusted with relevant South African data, notably fuel consumption and diesel quality. In the Ecoinvent database carbon dioxide and sulphur dioxide emissions are calculated on the basis of fuel consumption. For sulphur dioxide emissions it is assumed that all sulphur in the fuel is transformed completely into SO_2. Similarly, for carbon dioxide emissions, all carbon in the fuel is assumed converted to CO_2. The remaining emissions of carbon atoms in the form of carbon monoxide, volatiles and particulates are not subtracted. All other emissions in the Ecoinvent truck operation inventories are given in g/km, and are from various sources.

It is thus possible to adjust the fuel consumption and the emissions of CO_2 and SO_2 without compromising the integrity of the Ecoinvent data record. The emissions of SO_2 and CO_2 are calculated using the following values for South African diesel:

- sulphur content of 500 ppm (the legal maximum in South Africa under recent legislation).
- carbon content of 20.2 kg/GJ
- calorific value of 43 MJ/kg.

Fuel consumption is taken from industry data (a major South African distribution company), and is assumed at 55 litres/100 km for trucks greater than 32 tons. This fuel consumption is for fully loaded trucks. To determine the fuel consumption of the trucks when travelling empty, the industry data was cross-referenced with values from the Road Transport Annex in the EMEP/CORINAIR Emission Inventory Guidebook. For 28-34 ton trucks the fuel consumption of the truck carrying no load was calculated to be 30 litres/100 km.

Truck maintenance is taken from the Ecoinvent inventory, which includes rough estimates for materials used (e.g. oil, air filters and tyres) and the electricity consumed in garages. No adjustments are made to the Ecoinvent record other than to change the electricity input to the South African electricity grid mix. For the frequency of maintenance, a kilometric performance of 540 000 km per truck is assumed (Ecoinvent figure) and the trucks are assumed to operate at an average of 50% load (i.e. fully loaded outward-bound journeys and empty return trips).

The Ecoinvent inventory for diesel supply is also adjusted to better represent South Africa, primarily with respect to the source of crude oil, and the consequent transport steps to, and within, South Africa. Approximately 74% of South Africa's crude oil supply is from the Middle East (primarily Saudi Arabia and Iran), 22% is from Africa (Nigeria, Angola and Cameroon) and the remaining 4% is from domestic sources. The capacity of South Africa's six major refineries is used to estimate transport distances (to place the location to which crude oil is transported and from which diesel is transported), and also to estimate the share of synfuels (together Sasol and PetroSA make up 28% of refinery capacity, in crude oil equivalents). No data is available on the production of diesel from coal or gas, so

the same production route as the crude oil sourced from Africa is assumed, however the long distance transportation of crude oil by transoceanic tanker is removed from the inventory. Thus, the source of crude oil for production of diesel and the Ecoinvent inventory used to estimate its environmental profile are as follows:

- 54% "Crude Oil, production Middle East, at long distance transport"
- 16% "Crude Oil, production Niger Delta, at long distance transport", used to estimate non-domestic African sources.
- 30% "Crude Oil, production Niger Delta" used to estimate domestic sources.

As a consequence the overall resource use of crude oil is overestimated in the results (where coal or gas should be indicated instead). However, this was thought to be better than indicating a "free" energy source, i.e. merely to exclude the synfuel component of SA fuels.

The diesel fuel data record further assumes that 90% of crude oil and refined fuel is transported by pipeline in the provinces covered by Transnet's pipeline network (KwaZulu-Natal, Free State, Gauteng, North West and Mpumalanga). The transport of the remaining 10% is broken down between rail (40%) and road (60%). The same breakdown between road and rail is assumed for the bulk transportation of fuel in those provinces not covered by the Transnet pipeline network. In all provinces, fuel is assumed to be transported a further 100 km by road from major fuel depot to filling station.

5.3 Data Validation

To validate the data the following steps were followed to rectify irregularities:

- Figures and equations were checked to ensure data and mathematical correctness.

- Assumptions made for methods of calculating information from the raw data were not always appropriate within the South African context. They were checked and values were correctly re – calculated to take this context in to account.

5.3.1 Mass and Energy Balances

Mass and energy balances can be used to validate data. However, this was not done for this study due to the nature of the data collected. Mass and energy inputs require accurate and comprehensive allocations of resource and energy inputs, Sevitz (2003). Production figures and best estimates provided by the relevant personnel were used.

5.3.2 Assigning data values

Assumptions were necessary so that values for data could be decided upon or calculated. ISO 14041:1998 describes a generic process of assigning values to data:

- A "non – zero" data value which is justified
- A "zero" data value if justified
- A calculated value based on the reported values from unit processes employing similar technology
- The treatment of missing data must be documented

This process was employed as far as possible for the relevant data obtained and used.

5.4 Capital Equipment

The machinery used in the process was not accounted for. According to the Association of Plastics Manufacturers in Europe (APME, 1999), this omission is not thought to introduce any significant errors, and is usually less that 1% of the

total system energy. APME explains, "although the energy and associated burdens needed to construct machinery and buildings are high. The total throughput of components in their lifetimes is such that the proportion of these burdens attributable to each component is trivial". Therefore, impacts related to capital equipment were not included.

5.5 Boundary Selection and Cut – off ratios

From Goal and Scope Definition the relative contribution of each input to the product must be known. This is so that one can determine which upstream processes will be analysed. Selection of a cut-off ratio is crucial so that upstream impacts for input values below this cut-off ratio are not unnecessarily analysed. The higher this ratio, the higher the impact inaccuracy. This also means that a greater number of processes are not analysed for upstream impacts.

The cut-off ratio is percentage of:

- Product weight
- Economic value
- Environmental impact

or any combination.

Selecting a cut-off ratio is normally based on experience, time and the availability of data. Understanding the cut-off ratio and how it affects the conclusions of any study need to be understood. However this is still a very subjective process, Sevitz (2003).

The Relative Mass Energy – Economic (RMEE) is a statistical method developed by Reynolds et al, (2000 b). This method determines quantitatively what effects different ratios have on the conclusions of a study. Table 5.2 indicates the fraction of true or total environmental outputs for different cut off ratios (taken from Reynolds et al, 2002b). Upper and lower 95% confidence intervals were also calculated which shows the degree of confidence in using the ratio.

Table 5.2: Mean and 95% confidence intervals of the fraction of total environmental output for different cut off ratios (Reynolds et al, 2002b)

	Percentage of True (or Total) Environmental Output		
Cut off Ratio	**Mean**	**95% Upper Interval**	**95% Lower interval**
0.00	100.00	100.00	100.00
0.05	99.38	99.97	96.97
0.10	98.37	99.96	91.40
0.20	96.16	99.90	80.50
0.25	94.74	99.85	74.60
0.50	87.9	99.57	42.67

Table 5.3, extracted from Reynolds et al (2000a) is the qualitative description of the level of detail and application for using different cut- off ratios. This table complements Table 5.2 and is useful when one has limited experience with LCA's.

Table 5.3: Qualitative descriptions of cut-off ratio implications (Reynolds et al, 2000a)

Cut-Off Ratio	Level of Detail Required	Application
0.20	Generally captures only primary energy, material and cost inputs to the system. Typically eliminates need to investigate most unit processes of capital construction and ancillary materials.	High level comparisons of systems. Compiling preliminary results. Identifying primary unit processes for design improvement.
0.10	Requires enough detail to include significant ancillary inputs Allows practitioner to investigate and understand the implications of more detailed design improvements.	Internal corporate decision making and overall design improvement
0.05	Provides a very detailed analysis often including the cost and environmental implications of construction facilities Requires substantial resources to complete the life cycle inventory.	Public claims for superiority of one system over another. Assessing systems for environmental output credits Detailed engineering design improvements.

In this study:

- The Boundary is typical LCA "boundary with nature" - inputs are from the environment (e.g. hard coal in ground) and emissions are final emissions to the receiving environment are included.

- For the cut off ratios none were used explicitly. All the inputs for which data was available were included in the LCA model.

CHAPTER 6: IMPACT ASSESSMENT

Inventory Analysis produces large quantities of data with respect to the use of raw materials through to releases to the environment throughout the process of the product life cycle. Simple aggregation and direct comparison cannot be used for this data, e.g. one kilogram of one type of air pollutant has vastly different health and environmental effects from one kilogram of another air pollutant (Sevitz, 2003).

Impact assessment methodologies were developed to convert the individual data (through multiplying factors, potentials or damage factors) into comparable values so that results may be evaluated and interpreted (Curran, 1996).

This study will determine which products are the environmentally preferable alternative and individual categories as well as aggregated groups of the characterisation stage will be compared.

6.1 Using Software

Data from the processes within the system boundaries initially defined were entered into an LCA software programme, SimaPro version 7.1.5. Four impact assessment methodologies, Impact 2002 (chosen method), Ecopoints, Eco-indicator 95, Eco-indicator 99, have been used to determine if any consistency exists across the methods that would indicate the usefulness of the scores.

6.2 Results of Impact 2002+ Methodology

6.2.1 Mid-point impacts

A comparison of the three emulsion processes according to the IMPACT 2002+ mid-point impact categories is given in Figure 6.1. In this figure the results are presented on a comparative basis (where the process with the highest impact is given a value of 100%), so it does not give any information on the relative magnitude of the impacts.

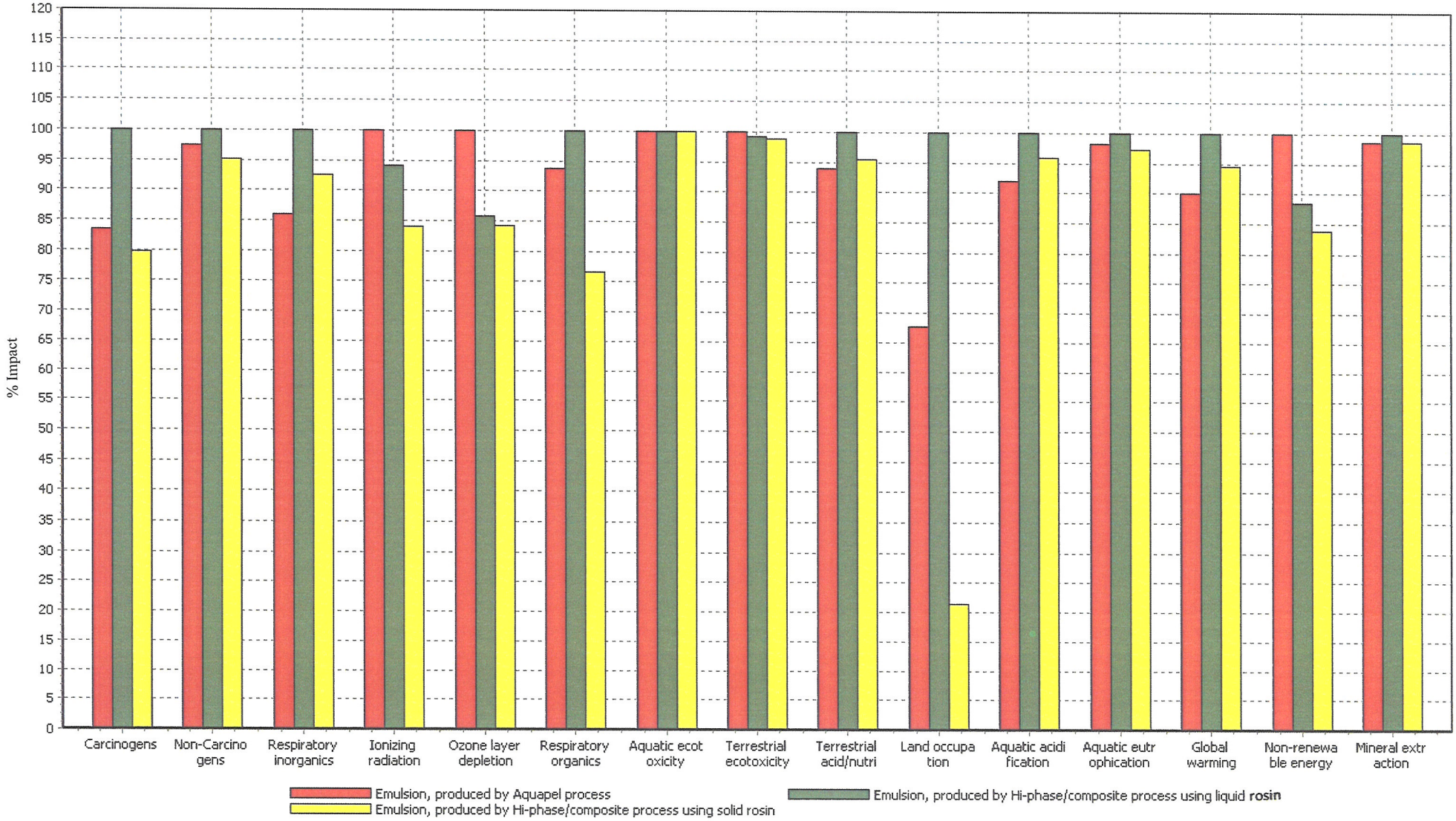

Figure 6.1 Comparison on IMPACT 2002+ mid-point categories (relative basis)

Figure 6.2 shows the normalised results. Although the normalisation data is for Western Europe and the results less relevant for a process in South Africa, normalised results are useful to give some indication of the relative magnitude of the impacts, i.e. for the production of emulsion, it would appear that toxicity impacts on terrestrial ecosystems is the most significant impact of the system, followed by the emission of respiratory inorganics, contribution to climate change impacts and its use of non-renewable energy resources. Of lower magnitude is its contribution to human toxicity (release of non-carcinogens) and its impact on aquatic ecosystems and its impact on ecosystems due to land occupation. Of relatively low importance are its contribution to human carcinogenic effects and its impact on terrestrial ecosystems due to acidification and nutrification, with all other impact categories showing negligible contributions there is no normalisation data for aquatic acidification and eutrophication, so these are not included in the analysis.

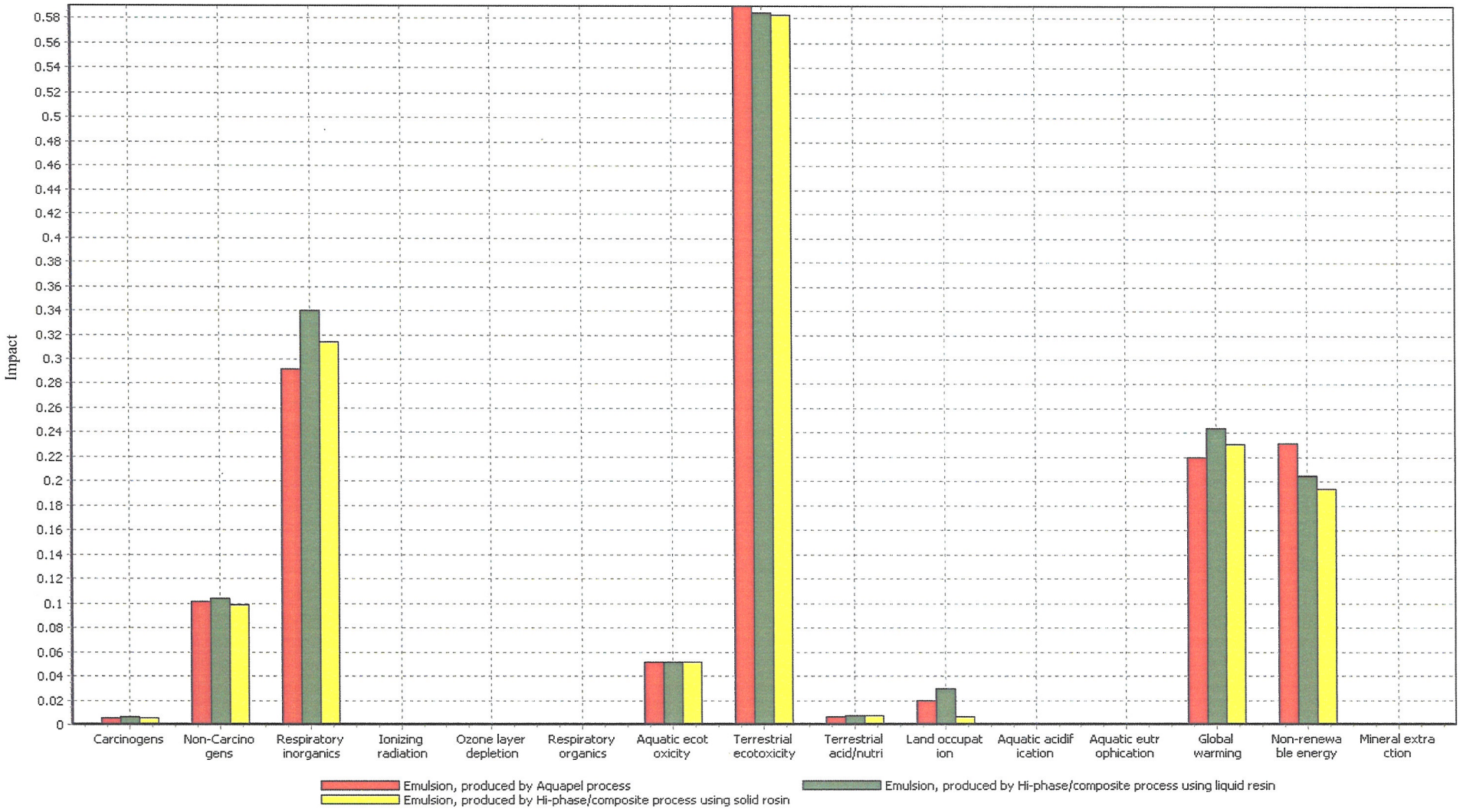

Figure 6.2 Normalised IMPACT 2002+ characterisation results (mid-point impacts)

6.2.2 Discussion of results of Impact 2002+ Methodology

Terrestrial Ecotoxicity

The three process have very similar contributions to terrestrial ecotoxicity, with the treatment of effluent (wastewater discharged from the emulsion process) accounting for the majority of this impact in all three processes. The slightly higher contribution to this impact by the Aquapel process is its higher use of starch, where the impacts from maize farming contribute 2.5% to this impact category.

Respiratory Inorganics

The emissions of respiratory inorganics (SOx, NOx and particulates) are primarily associated with electricity use (i.e. results from the high coal-fired component of South Africa's electricity grid mix). In all three processes, water treatment has the highest contribution to this impact (Aquapel process the highest contribution with the Hi-phase/composite process close behind), followed by effluent treatment in all three processes. The electricity used in the emulsion process itself has the next highest contribution in all three processes. The higher contribution to respiratory inorganics by the process using liquid rosin is due to a relatively high contribution from the production of tall oil, a relatively energy intensive process. Whilst both Hi-phase/composite processes have higher contributions to this impact than the Aquapel process due to their higher steam and electricity usage.

Global Warming

Global warming or climate change impact is similarly related to the coal-fired energy use of the systems. Thus, the same trends as for respiratory organics can be seen for this impact category (i.e. same ordering of the processes and very similar percentage contributions).

Non-renewable energy

The impact of the systems on non-renewable energy resources is also primarily related to their use of coal (and so electricity consumption). However, the Aquapel process shows the highest impact here because its raw material (wax) is also based on a non-renewable energy resource (crude-oil), whilst the raw material for the Hi-phase/composite processes (rosin) is bio-based.

Non-carcinogens

As for terrestrial ecotoxicity, effluent treatment accounts for the majority of this impact. The Hi-phase/composite process using liquid rosin has the highest contribution to this impact due to a contribution from tall oil production, whilst the higher use of starch in the Aquapel process accounts for its slightly higher contribution than the Hi-phase/composite process using solid rosin.

Aquatic ecotoxicity

The impact is strongly related to the high volumes of water used by the processes, particularly in the treatment of water used in the process (70%) and the treatment of effluent discharged from the process (30%). The impact is essentially equal from all three processes.

Land Occupation

The land occupation impact in the Aquapel process and the Hi-phase/composite process using solid rosin comes from the maize starch used in the process. The Hi-phase/composite process using liquid rosin has a higher impact because of the contribution of the production of tall oil (land for forestry). The process using solid rosin has only a low impact because it is assumed wild trees are tapped sustainably for their resin, whilst plantations are used to supply the Kraft process which produces the tall oil resin.

6.3 Damage Categories

Figure 6.3 shows the relative contributions of the three emulsion processes to the four damage categories considered by the IMPACT 2002+ method. This shows the relatively close performance of the three processes, with the process using liquid rosin showing slightly higher potential damages in three out of four of the damage categories. The explanation for the differences between the systems is given in section 6.3 (Appendix 14, IMPACT 2002+ damage category results per ton of emulsion produced for various model assumptions and parameter inputs). Here you see how the mid-point impacts are combined to yield these summarised results). The contributions to these damage categories are also shown in Figure 10, Figure 11 and Figure 12 in Appendices 10, 11 and 12 respectively, as well as in the network diagrams, Appendix 13.

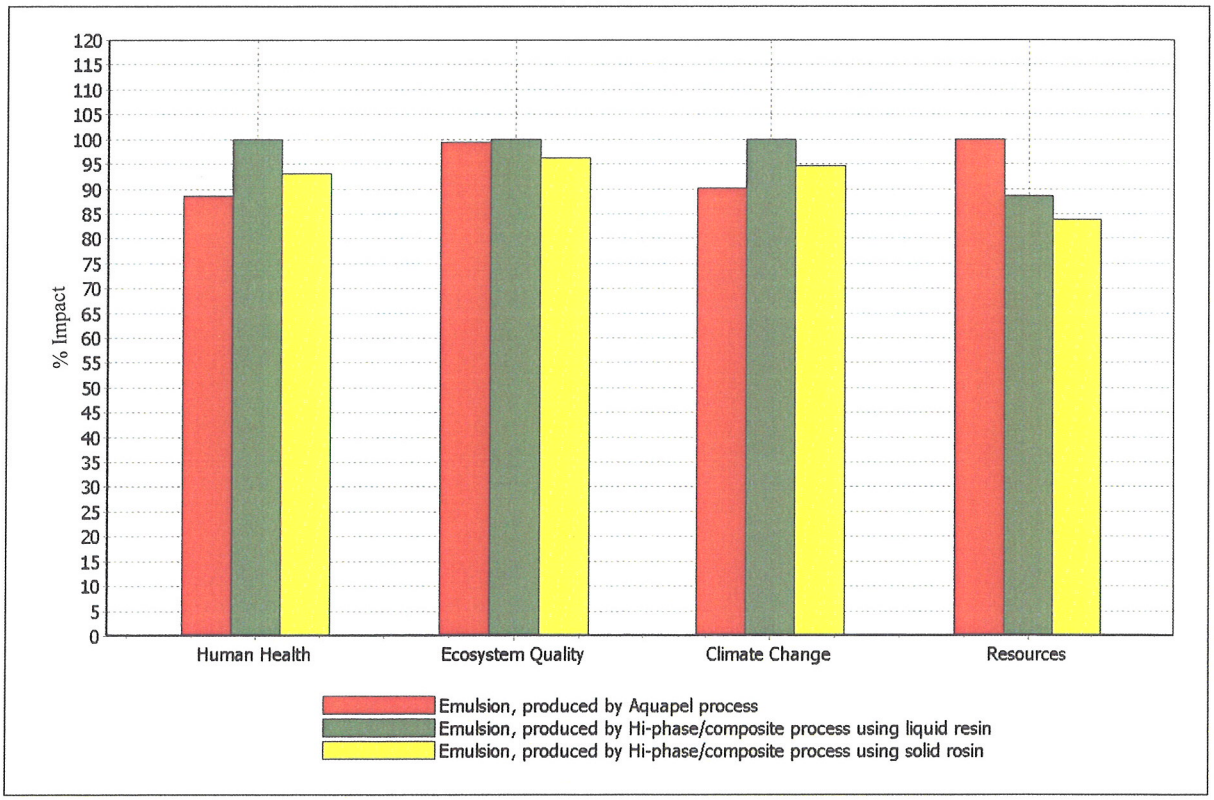

Figure 6.3 Potential relative contributions to the four IMPACT 2002+ damage categories.

6.4 Impact Assessment using different LCIA methods

The methods generally agree with each other at the characterisation stage, other than the use of different terminology, e.g. "winter smog" for "respiratory inorganics" and different combinations of impacts into a single category indicator occur.

A notable exception is the Greenhouse / Climate impact. The IMPACT 2002+ method does not credit the system for CO_2 taken up from air to become part of the product , e.g. in wood, whereas these other methods provide a negative score of -1 for "raw" CO_2 in air resulting in a Greenhouse "credit" for the system. Instead, IMPACT 2002+ provides no impact score for biogenic CO_2 and CH_4 emitted, i.e. these do not contribute to climate impacts in the method, whereas in the other methods biogenic emissions are given the same impact score as the fossil emissions. This accounts for the different climate profile of the systems when viewed with the different methods, especially the Hi-phase/composite process using liquid rosin, which has a relatively high input of bio-resources, wood used in the Kraft process, of which the tall oil is a by-product. The other methods agree with each other and are in line with the Intergovernmental Panel on Climate Change (IPCC) factors, and therefore arguably provide a more commonly accepted view of the relative climate impact of the systems than that obtained with the IMPACT 2002+ method.

6.4.1 Impact Assessment using the Ecoindicator 95 methodology

Normalised results using this method attach a high importance to eutrophication, Figure 6.4 and Figure 6.5. However, this method is relatively old and the high emphasis on eutrophication in the normalisation probably does not represent current thinking, as eutrophication/nutrification is generally not considered an impact of high relevance because it is very site-dependent (i.e. its importance depends strongly on the sensitivity of the receiving environment).

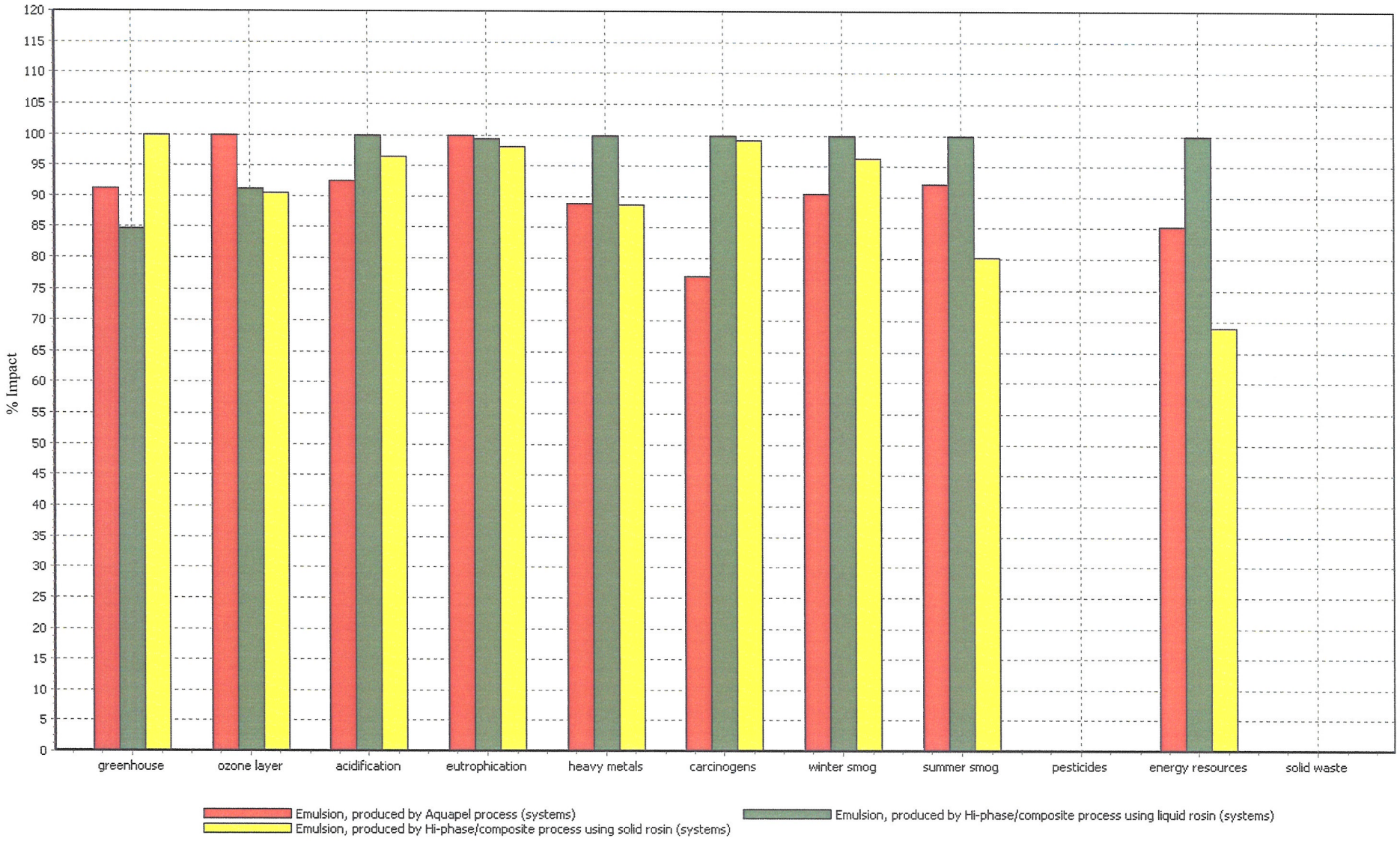

Figure 6.4 Comparison of 1 ton emulsion produced using Eco-Indicator 95 (relative basis)

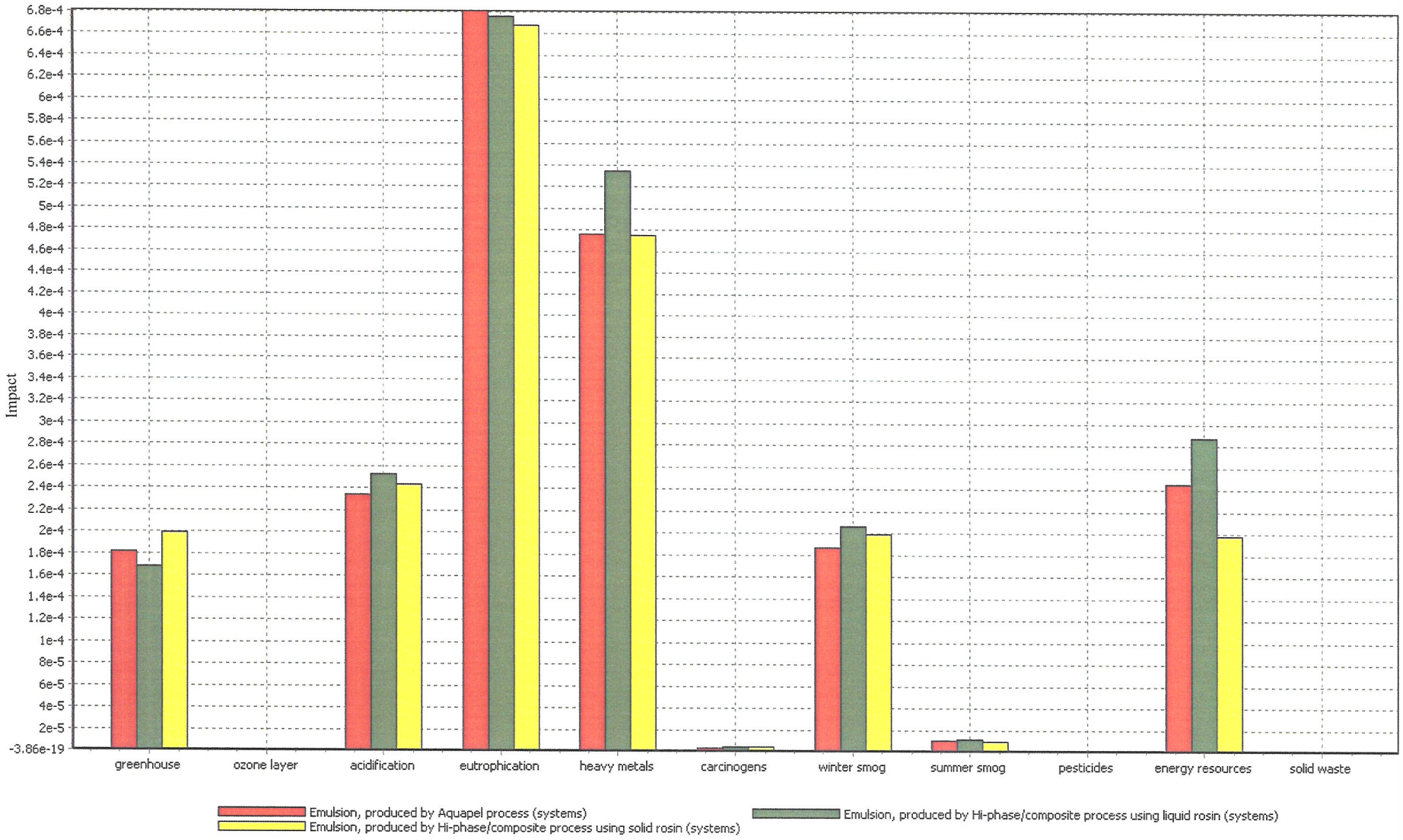

Figure 6.5 Comparison of 1 ton emulsion produced using Eco-Indicator 95, normalised results (normalisation based on 1990 levels for Europe excl. former USSR, with missing data extrapolated using GNP's)

6.4.2 Impact Assessment using the Ecoindicator 99 methodology

The three Ecoindicator 99 methods give practically identical characterisation results to each other, other than for the fossil fuels indicator, where the Hierachist, Figure 6.6, version places a higher impact score on crude oil than the Egalitarian version, Figure 6.7, whilst the Individualist version, Figure 6.8, does not consider fossil fuel use as an impact at all. Thus, when viewed at the level of normalised damages, the trends between the systems are the same, but with the Egalitarian version attaching a high importance to resources, and the Individualist version attaching a high importance to human health impacts and very low importance to resources (where it only considers mineral and not fossil fuel resources). The Hierachist version is generally the default version of the Ecoindicator 99 method as it takes the middle-road between these two extreme perspectives. The Hierachist version also gives very similar results to the IMPACT 2002+ method, as the IMPACT 2002+ damage assessment is very much based on this method, other than it splits out climate change from human health which are considered together in Ecoindicator 99.

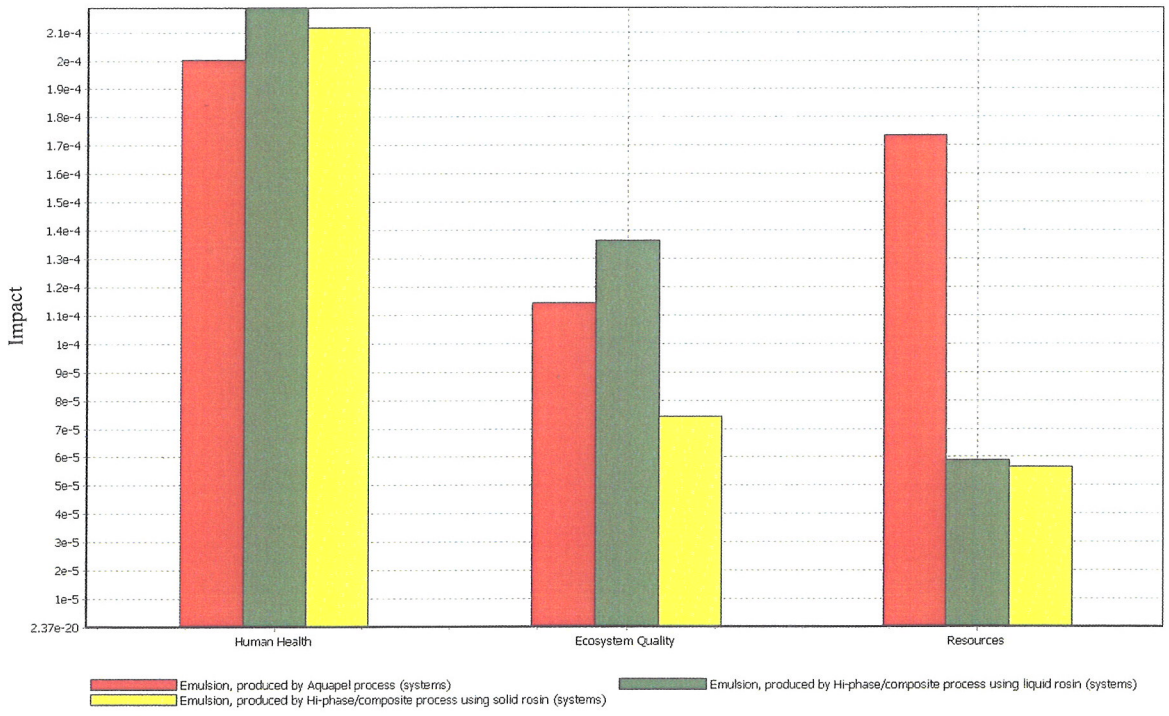

Figure 6.6 Normalised damage results for 1 ton emulsion produced using the Eco-indicator 99 method, Hierachist perspective

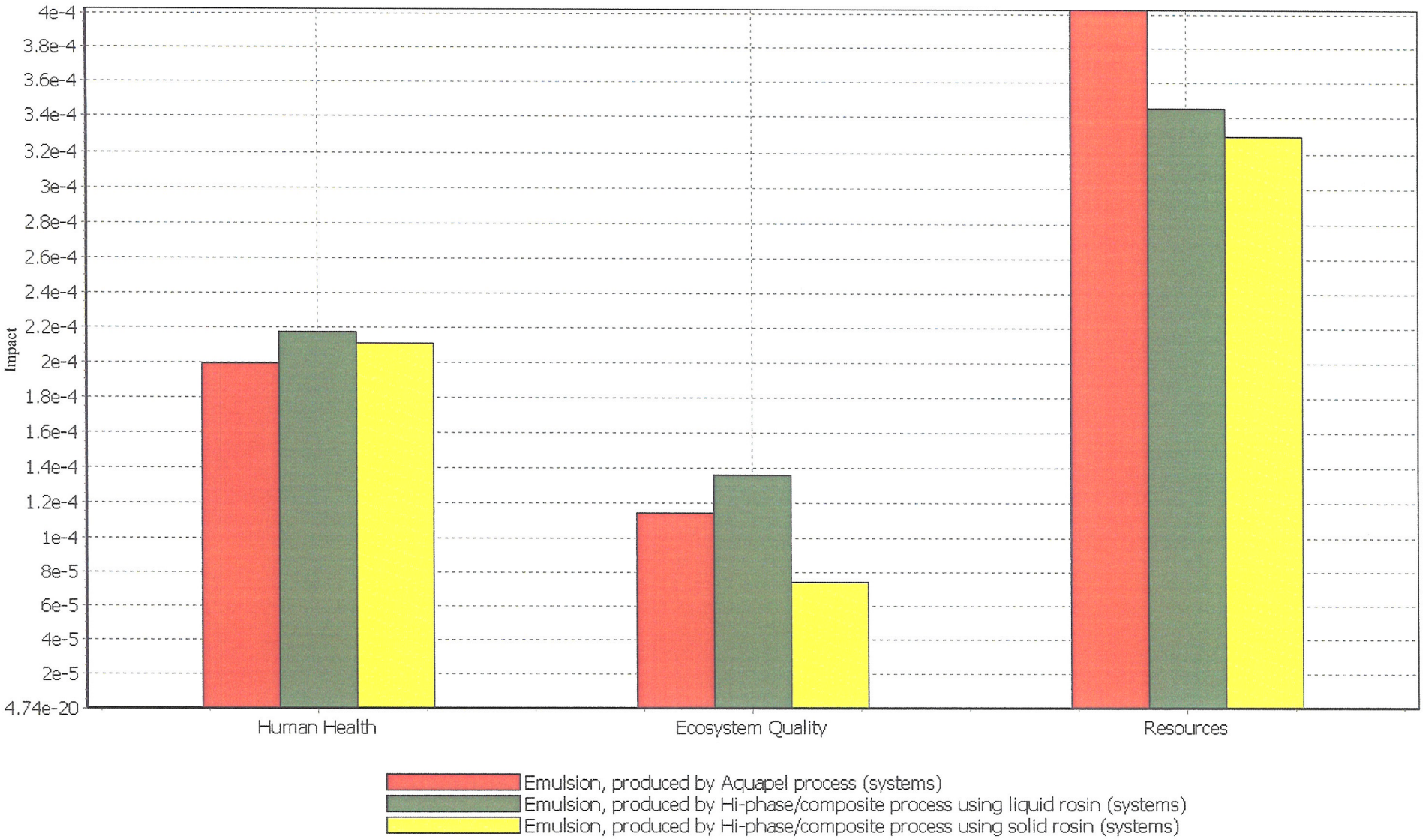

Figure 6.7 Normalised damage results for 1 ton emulsion produced using the Eco-indicator 99 method, Egalitarian perspective

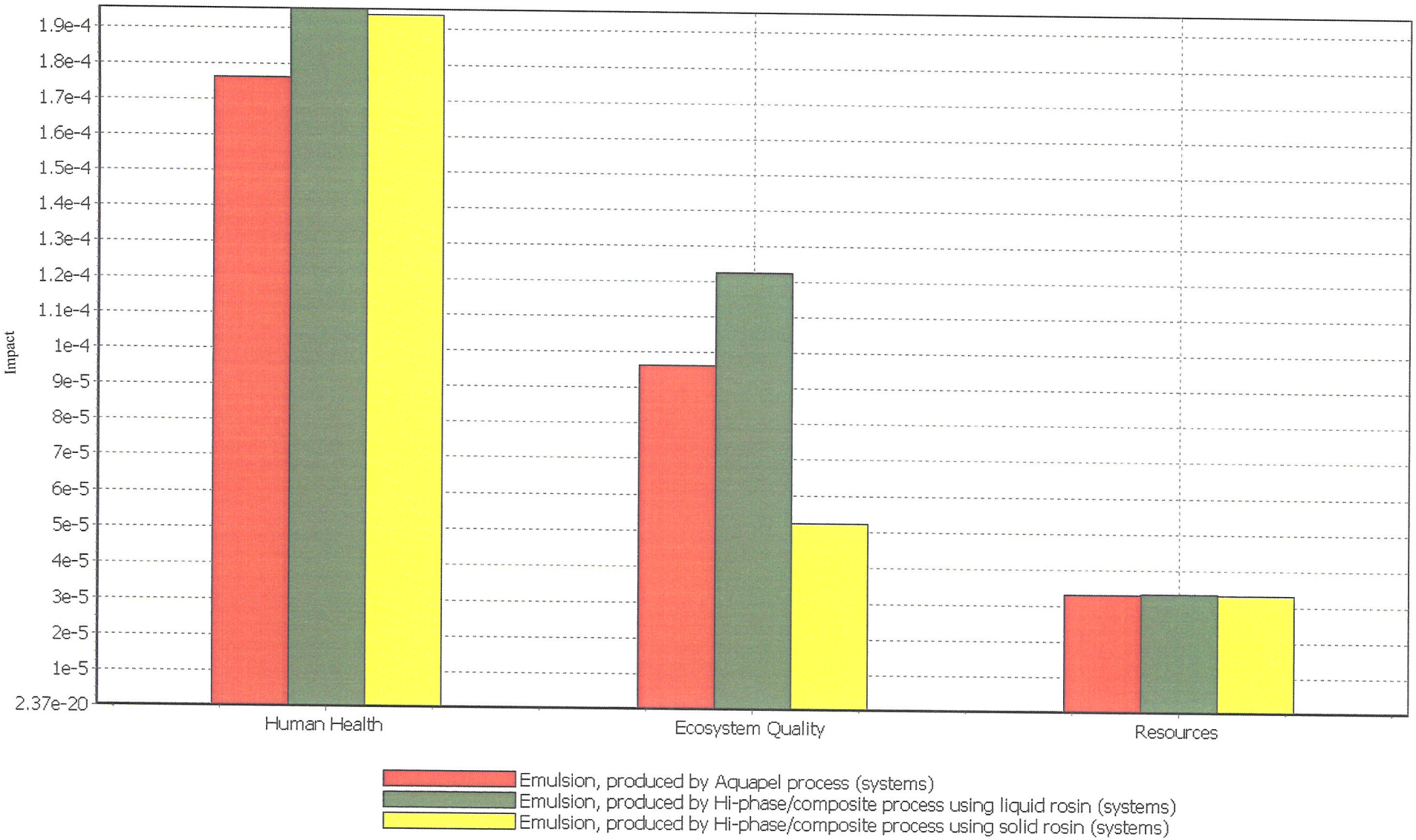

Figure 6.8 Normalised damage results for 1 ton emulsion produced using the Eco-indicator 99 method, Individualist perspective

6.4.3 Impact Assessment using the Ecopoints from BUWAL methodology

The Swiss Ecopoints method, Figure 6.9, provides a different perspective, in that a considerably larger number of impact categories are considered much closer to inventory level. However, as all the methods are based on the same inventory results, when the aggregations used in the different methods are explored, the trends between the systems agree with those found by the other methods.

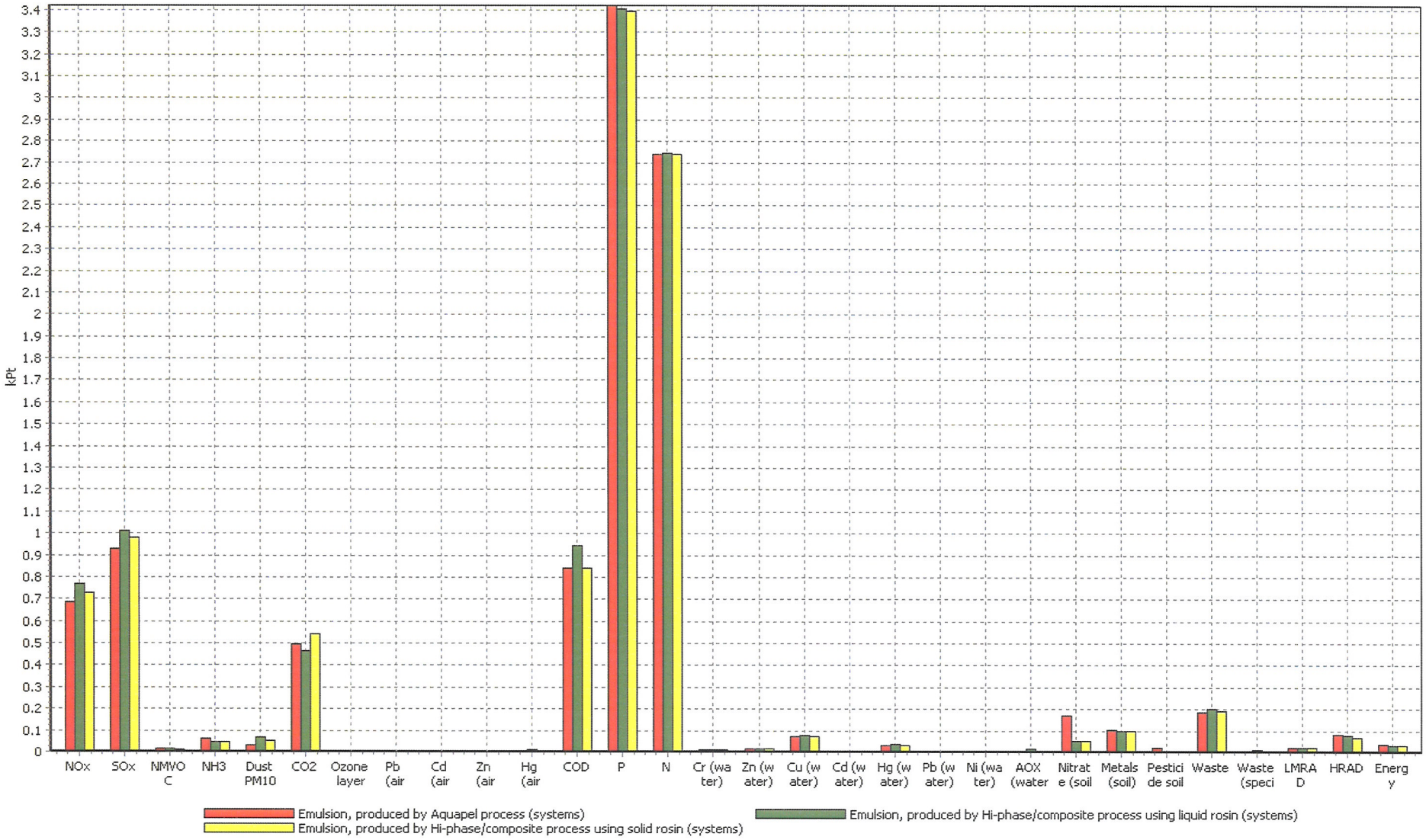

Figure 6.9 Results for 1 ton emulsion produced, in Swiss Ecopoints (normalisation based on actual emissions)

6.5 Data Quality Analysis

ISO 14042 (2000) describes three different techniques, Contribution Analysis, Uncertainty Analysis and Sensitivity Analysis to gain a better understanding of the significance of the impact analysis results.

The contribution analysis is a statistical procedure which identifies data that would have the greatest contribution to the indicator result. The uncertainty analysis describes the statistical variability in data sets in order to determine if indicator results from the same impact category are significantly different to each other. The sensitivity analysis measures the extent to which changes in the inventory results, characterisation, etc influence the indicator results.

For this company commissioned study, it was not possible to perform a meaningful statistical analysis as the nature of the errors are systemic and not due to randomness. Most of the data was supplied by the company, including the assumptions made, the Ecoinvent database and the databases contained within Simapro.

However, a contribution analysis was conducted showing the results that have the most significant effect on the indicator results. The uncertainty analysis discussed in the interpretation stage is more of a qualitative nature. Thus, more of a qualification of the data rather than an analysis of the data.

Sensitivity of the characterisation models was also conducted to ascertain which of the processes have a significant contribution to the overall impact of the life cycle analysis of the different emulsions.

6.6 Overall Discussion of results

6.6.1 Contribution Analysis

A detailed contribution analysis is discussed in section 6.3, but the most significant categories are restated.

A comparison of the three emulsion processes according to the IMPACT 2002+ mid-point impact categories is given in Figure 6.1. In this figure the results are presented on a comparative basis (where the process with the highest impact is given a value of 100%), so it does not give any information on the relative magnitude of the impacts. Figure 6.2 shows the normalised results. This is performed to highlight the significance that certain processes contribute towards the overall impact.

For the production of emulsion, it would appear that toxicity impacts on terrestrial ecosystems is the most significant impact of the system, followed by the emission of respiratory inorganics, contribution to climate change impacts and its use of non-renewable energy resources.

6.6.2 Sensitivity Analysis

Various key model assumptions were varied in sensitivity analyses. The results are summarised in Table 6.1. These show the results on a relative basis (result for scenario divided by result for base case scenario) so as to easily see which assumptions change the results to a significant degree. The data from which this table is calculated is given in Appendix 14.

Table 6.1 Damage category results per ton of emulsion relative to base scenario for various model assumptions.

Damage category	*Water & electricity allocation by batch*	*Water variation* Low	high	*Steam variation* Low	high	*Steam calc. by batch*	*Cooling water evap. loss: 50%*	*economic allocation in liquid rosin production*	*Including forestry in gum rosin production*
	Aquapel process								
Human Health	1.5	0.7	1.3	1.0	1.0	1.0	0.8	-	-
Ecosystem Quality	1.1	0.6	1.4	1.0	1.0	1.0	0.6	-	-
Climate Change	1.6	0.8	1.2	1.0	1.0	1.0	0.9	-	-
Resources	1.6	0.8	1.2	1.0	1.0	1.0	0.9	-	-
	Hi-phase/composite process using liquid rosin								
Human Health	1.0	0.7	1.3	1.0	1.0	1.0	0.8	0.9	-
Ecosystem Quality	1.0	0.6	1.4	1.0	1.0	1.0	0.6	1.0	-
Climate Change	1.0	0.7	1.3	1.0	1.0	1.0	0.9	0.9	-
Resources	1.0	0.7	1.3	1.0	1.0	1.0	0.9	0.9	-
	Hi-phase/composite process using solid rosin								
Human Health	1.0	0.7	1.3	1.0	1.0	1.0	0.8	-	1.0
Ecosystem Quality	1.0	0.6	1.4	1.0	1.0	1.0	0.6	-	2.0
Climate Change	1.0	0.7	1.3	1.0	1.0	1.0	0.9	-	1.0
Resources	0.9	0.7	1.3	1.0	1.0	1.0	0.9	-	1.0

Water and electricity allocation

The monthly water and electricity data are allocated to the emulsion products according the mass of particular product produced in that month (Figure 6.10). An alternative way of analysing the data would be to divide the total monthly electricity and water use by the total number of batches produced that month, i.e. this assumes producing a batch of Aquapel emulsion consumes the same amount of electricity and cooling water than producing a batch High-phase/composite emulsion. This considerably increases the impacts from the Aquapel process, as it gives it the same electricity and water requirements as a batch of Hi-phase/composite, but at a much higher per ton value. Not surprisingly, since the use of cooling water is shown to contribute so significantly to the impacts from the systems, this makes the Aquapel process perform more poorly against all damage categories than the Hi-phase/composite process.

It can be surmised that the actual allocation probably falls somewhere between the two, i.e. that power and water use is related to the duration of the batch (the two processes have very similar batch durations), but that it is also related to the size

of the batch (a single batch of Hi-phase/composite emulsion produces almost double the tonnage of product than a batch of Aquapel emulsion). The analysis does however show that because water use has such a high contribution to the overall results it might be necessary to measure more precisely the separate water requirements of the two processes if any clarity on their relative environmental performance is to be obtained.

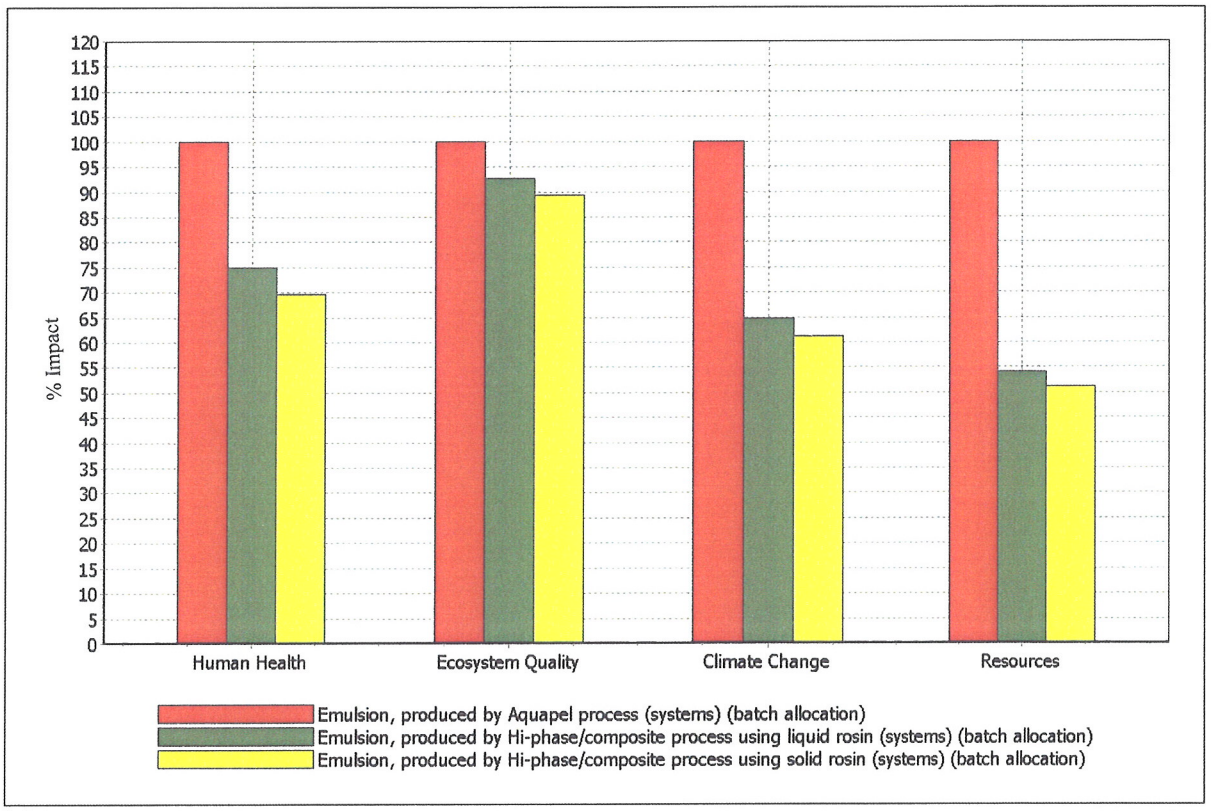

Figure 6.10 Potential relative contributions to the damage categories when electricity and cooling water are allocated per batch of emulsion produced (rather than on a mass basis).

Variation in water and electricity use

The base scenario results are calculated using the average water and electricity use for the monthly data provided (calculated over the eight months for which data are provided). To assess the variability in water and electricity use, the results are also calculated using the maximum and minimum data over the months. The water use is seen to be highly variable, and causes significant changes in the results, causing a 40% decrease/increase in ecosystem quality, and 20-30% changes in the other

damage categories. Electricity use, on the other hand is fairly stable, and variation in electricity use has a negligible effect on the results.

Variation in steam use

The use of steam has a rather low contribution to the overall system results, and thus, even with fairly high variation in steam usage applied (the minimum and maximum daily values), the effect on the results is negligible. An alternative way of calculating steam usage, i.e. on a batch rather than an hourly basis (where the minimum daily usage is assumed to correspond to a batch of Aquapel emulsion and the maximum daily usage a batch of Hi-phase/composite), was also applied, and likewise found to have no discernable effect on the results.

Cooling water evaporative loss

Only overall water usage data are provided, thus a best guess is made of the percentage of this water that evaporates and thus does not end up as effluent in municipal drains. In the base scenario a value of 10% is applied, whilst for sensitivity a value of 50% is applied. This parameter is found to have a significant effect on the results, decreasing the potential impact on ecosystem quality by 40% and the other damage categories by 10-20%. However, since the same parameter value is applied in all systems, the parameter is not important in the relative comparison between the systems.

Allocation in liquid rosin production

The production of tall oil is a by-product of the Kraft process, and thus the burdens of this process need to be allocated between the pulp (the primary product) and the tall oil (a by-product). In the base scenario, a mass allocation is applied, resulting in 2% of the burdens of the Kraft process being allocated to the tall oil. However, if an economic allocation is applied (i.e. allocation is based on the economic value of the two products), only 0.2% of the burdens are allocated to the tall oil. For the overall Hi-phase/composite process using liquid rosin this causes a 10% decrease in its potential contributions to human health, climate change and resource depletion. The Kraft process is a relatively polluting process (as it is energy intensive) and thus the change in allocation basis significantly

decreases the overall burdens of the Hi-phase/composite emulsion using liquid rosin relative to the process using solid rosin, Figure 6.11).

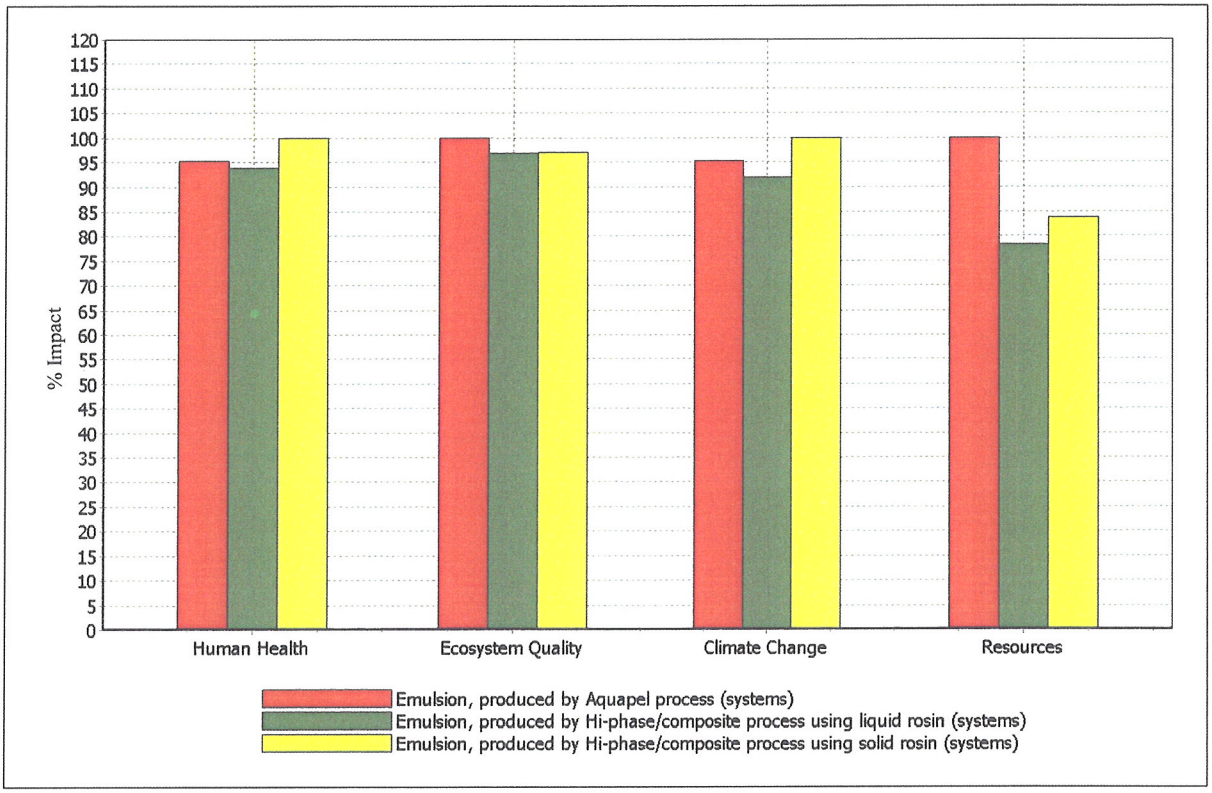

Figure 6.11 Potential relative contributions to the damage categories when an economic allocation basis is used in the manufacture of liquid rosin.

Assumptions in production of solid rosin

In the production of the gum rosin, it is assumed that the rosin is sustainably tapped from trees in natural forests. However, for sensitivity, an alternative scenario is investigated, in which it is assumed plantations are used instead (and thus the burdens of forestry are included in the system). It is assumed that approximately 200 trees are needed to yield a ton of oleoresin, from which it is calculated that approximately 245 m^3 of wood is required. A volumetric measurement of the wood required is needed to relate the number of trees under cultivation to the Ecoinvent inventory "Softwood, standing, under bark, in forest". Including forestry in the burdens of solid rosin production has a large effect on land occupation, and doubles the potential effect of the Hi-phase/composite

process using solid rosin on ecosystem quality. It has a negligible effect on all other impacts, Figure 6.12).

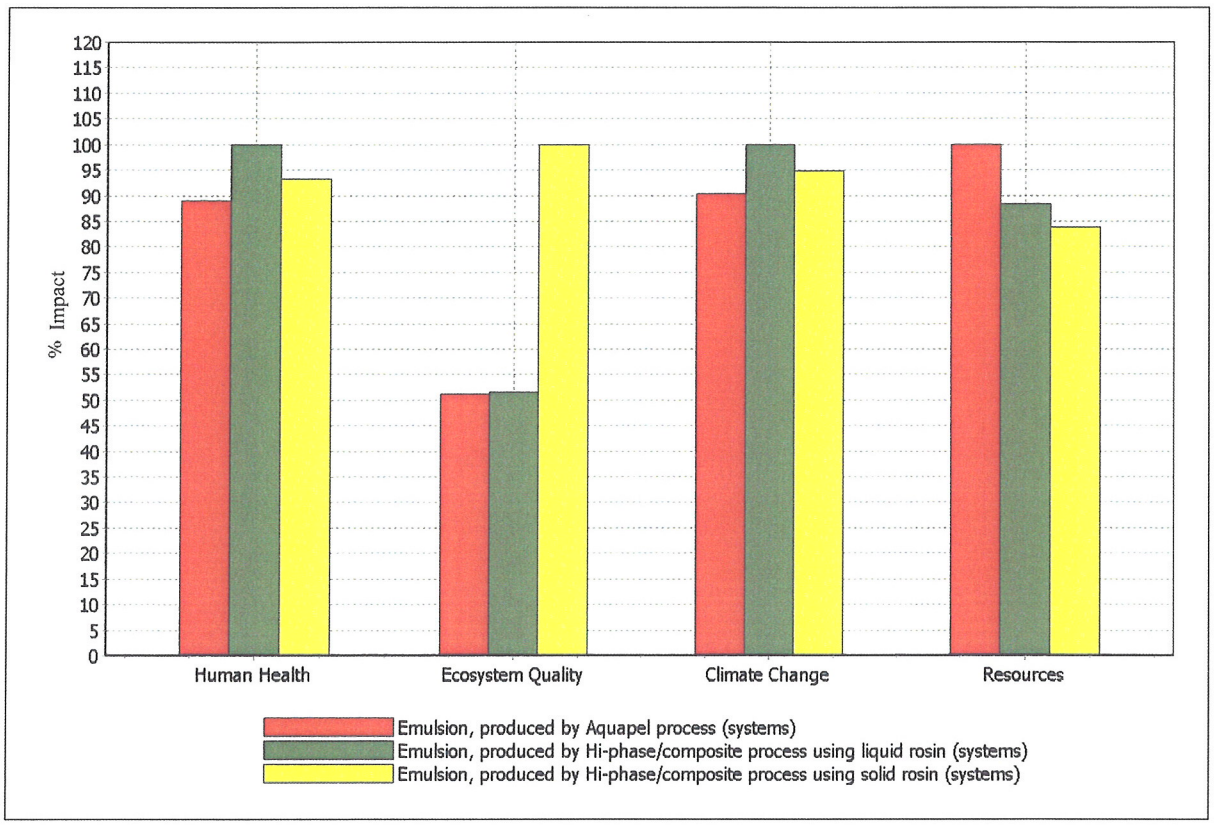

Figure 6.12 Potential relative contributions to the damage categories when solid rosin production is assumed to be from plantation rather than natural forest.

6.7 General limitations of impact assessments

As ISO 14042 (2000) describes, the impact assessment chapter addresses only the environmental issues that are identified in the goal and scope. Or in this case, only those issues identified to be relevant by the respective impact assessment methodologies has been chosen for this study. The limitation of this is that an impact assessment is therefore not a complete assessment of all environmental issues of the product system under study (Sevitz, 2003).

The impact assessment is, wherever possible, a technical and scientific procedure. However, value-choices are used in the selection of impact categories; indicators, damage factor and characterisation models; and in normalisation, grouping and

weighting of the categories. This subjective nature reduces the credibility of LCA's as an environmental management tool.

Indicator results may vary due to differences such as those between the characterisation model and the corresponding environmental mechanism, differences in the use of simplifying assumptions and differences within available scientific knowledge.

CHAPTER 7: INTERPRETATION

This is the final chapter of the LCA and the results from the Inventory Analysis and the Impact Assessment chapters are analysed relative to the Goal and Scope Definition chapter. The results are qualified and evaluated, conclusions are formed, limitations are stated and the recommendations put forward.

Interpretation of the technical chapters, i.e. Inventory Analysis and Impact Assessment, is a process of communication in a format that is understandable and useful to management and decision-makers in any industry.

7.1 Evaluation

7.1.1 Completeness and Consistency Check

When comparing the impacts of three emulsion processes it is necessary to bear in mind the completeness and consistency of the inventory models, as well as the uncertainty in the data. The underlying inventory models are described in Chapter 5.

The Ecoinvent database used to supply the inventory models for upstream and downstream processes is of high quality and has a number of internal checks and reviews that take place before the data is published. The Ecoinvent data is therefore as consistent and complete as any LCA database available and is arguably the most complete and consistent. Any adjustments to the Ecoinvent data have been made consistently across the data models used in the three processes and therefore does not affect the consistency of the data, but merely increases its relevance for use in the study in a South African context.

The models of the emulsion processes themselves are much less complete than the Ecoinvent models, i.e. they contain information only on the process inputs and liquid effluent, e.g. no emissions from melting the rosin are included in the model, only those emissions "embodied" in the use of electricity and coal to generate

steam. However, no data has been provided on fugitive emissions for these processes. Nevertheless the same level of completeness is applied for the three emulsion processes, so the fact that the inventory models might be incomplete is less significant for a comparison between the systems (i.e. the comparison is consistent).

The biggest completeness and consistency concern arises in the production of the rosin and wax (the major material input into the emulsion processes). The wax used in the Aquapel process and the liquid rosin used in the Hi-phase/composite processes are both modelled with Ecoinvent data (adjusted where possible to increase their relevance to South Africa). However, no LCI data on solid rosin production is available in the Ecoinvent database or any of the other LCA databases searched. This meant an LCI on solid rosin production had to be built up from basic process information and the resultant inventory model is at the same level of detail as the emulsion production process, i.e. major process inputs included but no emissions from the process itself. In this case, this lower level of detail is much more significant for a comparison between the systems as the corresponding Ecoinvent models used for liquid rosin and wax production are much more complete. However, as far as can be told from the literature search conducted on solid rosin production, the process is relatively low impact (i.e. merely washing and distilling a natural product), so the lack of completeness is judged not to have too large an effect on the comparison.

The production of wax on the other hand, whilst relatively detailed (the Ecoinvent process for paraffin is used) is problematic in that its relevance to the process is questionable. Firstly there is the fact that data on the production of paraffin is used to approximate the production of paraffin wax, and secondly, there is the much larger issue of the wax being coal-based rather than crude-oil based. A wax based on coal (i.e. from SASOL) is expected to have higher emissions (especially CO_2, SO_2, heavy metals, etc) and would result in poorer performance in all impact categories where such emissions play a role, e.g. climate change, respiratory inorganics and terrestrial acidification/nutrification. The difference between the

Aquapel emulsion and the Hi-phase/composite is likely to decrease slightly in those impacts where the Aquapel process is shown to have lower impacts (i.e. the difference between the systems become less significant in human health and climate change damages), but increase slightly (become more significant) where the Aquapel emulsion shows poorer performance (this is only relevant to the emission-related impacts, e.g. not land occupation or resource use).

7.1.2 Uncertainty Analysis

Given the discussion on inconsistencies between the data used in the production of their primary material inputs and especially since the three emulsion processes show very similar environmental profiles, the differences between them are probably within the uncertainty of the systems, systemic in nature. No quantitative uncertainty analysis has been conducted in this study, but a general rule of thumb is that differences of less than 15-20% between the systems are unlikely to be statistically significant, i.e. have a probability of greater than 95% and even higher for those impacts where the modelling is associated with high uncertainty (the human toxicity and ecotoxicity impact categories). In those impact categories related closely to inventory-level emissions which are calculated with a relatively high degree of accuracy (e.g. CO_2, SO_2, etc.), statistical significance might be obtained with differences of around 10-15%.

Thus, a look at Figure 6.3 shows that very few of the differences between the Aquapel emulsion and the Hi-phase/composite emulsion systems meet these criteria. First, the difference in climate change between the Hi-phase/composite emulsion using liquid rosin and the Aquapel emulsion is significant (10% difference) and second the difference between the resource use of the Hi-phase/composite emulsions and the Aquapel emulsion is significant (12% difference).

On the impact level, Figure 6.2, the differences are more significant, with significant differences between the Hi-phase/composite emulsion using liquid rosin and the Aquapel emulsion in carcinogens, respiratory inorganics, land

occupation, climate change and non-renewable energy. Comparisons between the Aquapel emulsion and the Hi-phase/composite emulsion using solid rosin are much weaker, with only differences in land occupation and non-renewable energy significant.

When comparing the Hi-phase/composite emulsions using liquid or solid rosin, none of the differences in damages, Figure 6.3, exceed 10%, i.e. no differences are likely to be statistically significant. On the impact level, Figure 6.2, their difference in land occupation is strongly significant, and their difference in respiratory inorganics likely to be significant. In all other impact categories it is likely to be too close to tell with any degree of confidence that the one system is truly better than the other.

The caution needed in interpreting the differences between these systems is further brought home by the sensitivity analyses. The way in which monthly electricity and water data are allocated between the processes has the potential to change whether the Aquapel or the Hi-phase/composite process has the higher damages. This shows that more detailed process data on water usage in the production of emulsion is required if a more accurate picture of the differences between these processes are to be obtained, i.e. the actual difference in cooling and cleaning water usage of the Aquapel process relative to the Hi-phase/composite processes.

The allocation of the burdens of the Kraft process to the tall oil (the by-product used in the production of liquid rosin) is also a very significant input to the model with the potential to reverse the relative performances of the systems. The change similarly reverses the relative performance of the emulsion using solid rosin to the emulsion process using liquid rosin, from better performance in all damage categories to worse performance. Another significant model assumption capable of reversing the findings is the assumption of whether to include forestry in the production of gum rosin. Both when comparing against the Aquapel emulsion and the Hi-phase/composite emulsion using liquid rosin, whether or not forestry is

included in the production of the solid rosin changes the Hi-phase/composite emulsion using solid rosin's performance in ecosystem quality from weakly better to very strongly worse than the other emulsion processes.

7.1.3 Sensitivity Analysis (Hot-Spot Identification)

The life cycle stages contributing the most to the life cycle impact is discussed for each emulsion. In general however, by far the most significant input into the emulsion production systems is their water use, both in terms of the energy use and impacts arising from treating the water, i.e. treatment processes to produce municipal tap water, in the energy use and impacts arising from treating the liquid effluent from the emulsion production. This is a surprising result, but is less so when the extremely high cooling water requirements of the processes are taken into account. The relatively low contribution from the energy requirements of the process may also be due to uncertainty in how the data on steam usage is applied in the model, i.e. data on steam usage has been supplied on a low usage and a high usage basis.

The usage of the water itself, as an important resource to be conserved in its own right, is not included in any of the impact or damage categories, but should also be noted as a highly important input to the emulsion production process. Water usage should therefore be targeted not only from the fact that its treatment processes produce a large share of the life cycle impacts, but also to reduce the consumption of what is a critical resource in a South African context.

In general, the identification of hot-spots is less sensitive to considerations of completeness and consistency in the data models than when comparing between systems. However, the relevance of the data models is important here. Thus, whilst the water treatment processes are shown to be of very high importance to the overall life cycle burdens from emulsion production, it needs to be remembered that these are modelled with European data. It has not been within the scope of this study to review the difference between South African and European water treatment processes, e.g. with respect to the electricity consumed

in these processes, and thus it is not possible to assess whether the importance of these processes are being overestimated (or underestimated) in the life cycle of emulsion production. Furthermore, water used in the emulsion production process is assumed to be municipal tap water and all effluent is assumed to be treated in municipal sewage treatment plants. The validity of these assumptions has not been verified.

The sensitivity analyses show that, because of the high contribution from water treatment processes, any variable that affects cooling water usage and effluent production is important for the certainty with which the hot-spots can be identified. The percentage of cooling water usage lost to evaporation is therefore possibly the most significant variable, as it affects the volume of effluent requiring treatment, shown to contribute very highly to the damage categories below. The model uses only a very rough estimate of evaporative loss as no data on effluent volumes has been provided; only overall water usage is known. Better monitoring on the plant of cooling water losses is therefore recommended to improve the accuracy of these predictions. Monthly variability in water usage is also found to be significant. The causes of this variability should be investigated so as to obtain a better understanding of water usage in the emulsion production processes (and consequently of the burdens arising from providing this water to the process, as well as of the burdens arising from treating the effluent leaving the process).

Aquapel emulsion

Treatment of the liquid effluent from the emulsion production process is important in all damage categories considered (Appendix 10), but especially so in ecosystem quality and human health. Provision of the water used in the process (tap water) is also seen to be important to all damage categories considered, but especially so in climate change and resource use. It is therefore very clear that by far the best intervention in the system to reduce life cycle damages would be to reduce the cooling water used in emulsion production.

The electricity used in the emulsion production process is found to be of the next highest importance in human health and climate change, and also important in resource use. Reducing electricity use in the process is therefore also a good intervention point to reduce life cycle burdens.

The production of the paraffin wax is the next highest contributor to resource use, after the water-related processes, but probably does not offer much scope for intervention into the emulsion production system, unless an entirely new raw material is sourced. It is also found to have a moderately important contribution to climate change and human health damages, which might be an underestimate if the wax is coal-based rather than crude-oil based, as assumed in the study.

The production of the maize starch used in the process is of relatively high importance to ecosystem quality (third highest), with appreciable contributions to all the other damage categories considered. Attempts to minimise the starch used in the process might therefore also provide a useful intervention point, especially with respect to reducing the impact on ecosystem quality.

The steam used in the process has only a small contribution to human health, climate change and resources (the sixth largest in each), but the steam usage data should be checked to be sure this input is as relatively unimportant as it seems.

Hi-phase/composite process using liquid rosin

As with the Aquapel process, treatment of the liquid effluent from the emulsion production process is important in all damage categories considered (Appendix 11), but especially so in ecosystem quality and human health. Similarly, provision of the water used in the process (tap water) is important in all damage categories considered, but especially so in climate change and resource use. It is therefore very clear that by far the best intervention in this system would be to reduce the cooling water used in the emulsion production process.

The electricity used in the emulsion production process is found to be of the next highest importance in climate change and resource use, and also important in human health. Reducing electricity use in the process is therefore also a good intervention point to reduce life cycle burdens.

Almost as important as electricity use and more so where ecosystem quality is concerned, is the production of the liquid rosin. This is because the Kraft process, in which it is produced as a by-product, is a relatively polluting process, so even the fairly small allocation of just 2% of the burdens from this process represents a significant contribution to the emulsion production system. The choice of allocation method is therefore important here, as it determines how high an importance should be attached to the production of tall oil.

The steam used in the process has an important contribution to human health, climate change and resource use (the fifth largest in each), and the steam usage data should be checked to be sure this input does not represent a more important intervention point.

The production of the maize starch used in the process has an appreciable contribution to all damage categories considered, and is of fourth highest importance to ecosystem quality. Minimising the starch used in the process might therefore also provide a useful intervention point to reduce life cycle burdens, especially with respect to reducing the impact on ecosystem quality.

Hi-phase/composite process using solid rosin

As with the other emulsion production processes, treatment of the liquid effluent from the emulsion production process is important in all damage categories considered (Appendix 12), but especially so in ecosystem quality and human health. Similarly, provision of the water used in the process (tap water) is important in all damage categories considered, but especially so in climate change and resource use. It is therefore very clear that, considering these treatment

processes together, by far the best intervention in the system to reduce life cycle burdens would be to reduce the cooling water used in emulsion production.

The electricity used in the emulsion production process is the second most important contributor to climate change and resource use, and the third highest contributor to human health damages. Reducing electricity use in the process is therefore the next best intervention point after cooling water reduction to reduce life cycle burdens.

With a fairly considerable step down in importance after electricity use, the steam used in the process is the next most important contributor to human health, climate change and resource use. However, minimising steam use might still represent a useful intervention point to reduce life cycle burdens.

The Hi-phase/composite process using solid rosin is the only emulsion system in which transport burdens have an appreciable contribution to the total life cycle damages. The shipping of the gum rosin from China has a relatively small but still significant contribution to human health damages (fifth largest) and less significant contributions to resources and climate change. Thus the location from which the gum rosin is sourced has some potential as an intervention spot to reduce life cycle burdens, although it should be remembered that the still rural production method from which the rosin is produced in China is responsible for the relatively low contribution from gum rosin production to the overall life cycle burdens. The burdens from shipping the gum rosin, the production of the gum rosin and the production of maize starch have reasonably similarly sized contributions to climate change, resources and human health, which are fairly small in comparison to the contributions from water treatment processes, and electricity and steam provision. They therefore offer only relatively small scope for intervention to reduce the life cycle burdens. Although still relatively small, the production of maize starch is the third highest contributor to ecosystem quality for the process using solid resin.

Thus as a second order estimate, it is thought that with the information and data supplied by the company, taking into account the assumptions made (company assumptions) that this study is reliable.

CHAPTER 8: CONCLUSION AND RECOMMENDATIONS

The quantity and quality of the data provided was of average standard. However, this could be greatly increased, if the company conducted its own LCA on their unit processes. The resources within the company are better known by the staff , thus enabling a more accurate and precise analysis to be undertaken and further enable a high quantity and quality of data to be captured. Therefore, enhancing the accuracy and reliability of local data and minimizing or eliminating the need for external and international data.

As a second order estimate based on the study it can be concluded:

When comparing the three emulsion processes according to the IMPACT 2002+ mid-point impact, the following have the most significant impacts in descending order:

- Toxicity Impacts on terrestrial ecosystems
- Respiratory Inorganics
- Climate Change
- Non Renewable Energy resources

It would appear that toxicity impacts on terrestrial ecosystems is the most significant impact. The emission of respiratory inorganics, i.e. the water treatment has the highest contribution to this impact (Aquapel then Hi-phase/composite) followed by effluent treatment, then electricity used in the emulsion process itself has the next highest contribution in all three processes. The higher contribution to respiratory inorganics by the process using liquid rosin is due to a relatively high contribution from the production of tall oil, a relatively energy intensive process.

Climate change is the third most significant contribution.

Non renewable energy resources for the Aquapel process shows the highest impact because its raw material, wax. It is also based on a non-renewable energy

resource, crude-oil, whilst the raw material for the Hi-phase/composite process, rosin, is bio-based.

When comparing the three emulsion processes according to the IMPACT 2002+ damage or end point impact categories the relative contributions of the processes shows the relatively close performance of the three processes. The liquid rosin process shows slightly higher potential damages in three out of the four damage categories. The explanation for the differences between the systems follows from the explanations given for the mid-point impact categories

The other assessment methods used, i.e. Ecopoints, Ecoindicator 95 and Ecoindicator 99 (Hierachist, Individual and Egalitarian perspectives), generally agree with each other at the characterisation stage. Except for the use of different terminology, e.g. "winter smog" for "respiratory inorganics" and different combinations of impacts into a single category indicator occur.

Also the Hierachist weighting set of the Ecoindicator 99 assessment methodology is a more conservative methodology. Therefore it is used to corroborate the final conclusions of the Impact 2002+ method. It also gives very similar results to the IMPACT 2002+ method, other than it splits out climate change from human health which are considered together in Ecoindicator 99.

However, if a sensitivity analysis is performed using varied scenarios a different result is produced. Thus, the allocation of the burdens of the Kraft process to the tall oil (the by-product used in the production of liquid rosin) is also a very significant input to the model with the potential to reverse the relative performances of the systems. The change similarly reverses the relative performance of the emulsion using solid rosin to the emulsion process using liquid rosin, from slightly better performance in all damage categories to slightly worse performance. Another significant model assumption capable of reversing the findings is the assumption of whether to include forestry in the production of gum rosin when comparing Aquapel emulsion and Hi-phase/composite emulsion using liquid rosin. In addition, whether or not forestry is included in the production of

the solid rosin changes the Hi-phase/composite emulsion using solid rosin's performance in ecosystem quality from weakly better to very strongly worse.

Additional studies need to be completed in order to take into account the following:

- The effect of precise water requirements and usage of the processes to establish clarity on the relative environmental performance
- Steam usage and consumption per process needs to be monitored regularly and methodically
- The Kraft process is a relatively polluting process (as it is energy intensive) and thus the change in allocation basis significantly decreases the overall burdens of the Hi-phase/composite emulsion using liquid rosin relative to the process using solid rosin. Further investigation is required to determine the exact impact.
- Future studies needs to include forestry and its downstream effects.
- The development of models for the emulsion processes and for both wax and rosin needs to be comprehensively conducted as no models exist at this point and time

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APPENDICES

Appendix 1: Rosin information

Raw Material information required for Simapro			
15-20 kg of tall oil per tonne of air-dried pulp	http://www.nzic.org.nz/ChemProcesses/forestry/4G.pdf		
4-5 kg oleorosin / tree / year 1000 kg oleorosin yields 770-800 kg gum rosin Export price in 2000 was 490 $/ton	http://www.cnchemicals.com/maindocs/marketreports/samples/forestchemicals/gumrosin_2001.htm		
Price tall oil : 90-100 $/ton Price kraft pulp: 880 $/ton	http://www.the-innovation-group.com/welcome.htm http://www.foex.fi/default.asp?navigate=pix_pulp_select.asp		
Diatomaceous earth, 0.5-0.6 kg/tonne of resin and oxalic acid 0.6-1.2 kg/tonne Each tank holds 1500-2000 litres of water which is sufficient for washing up to 20000 litres of res For still capacities of about 4-5 tonnes, distillation times vary between 90 and 150 minutes.	http://www.fao.org/docrep/V6460E/v6460e00.htm#Contents		
TALL OIL			
Mass allocation	1.96%		
Economic allocation	1000	kg pulp	$ 880,000.00
	20	kg tall oil	$ 2,000.00
			0.23%
GUM ROSIN			
per ton oleorosin			
product	800	kg gum rosin	
clay	0.6	kg	
oxalic acid	1.2	kg	
wash water (specific gravity 1.05)	0.10	m3	
steam (2 MJ/kg energy reqirements "AKD sizer from vegetarian fatty acids", ecoinvent unit proce:	2000	MJ	
distillation time	30	mins	
	4000	*MJ/hr*	
5	kg / tree / year		
200	approx. No. Trees to yield 1 ton oleoresin		
1.22	m3 per tree (14 inch diameter, 3 m high)		
244	m3 approx. wood area to yield 1 ton oleoresin		

Appendix 2: Process Data

PROCESS DATA

AQUAPEL PROCESS	**PER BATCH**		
Process Inputs	**Units**	**Ave Value**	**Notes**
Steam	see next sheet		2hrs 15 minutes. Assumed saturated steam. The nearest company generates 20 bar, but 5 bar is lost due to leaks.
Process water	tons	4.3	this is heated to 100 deg C, assume energy required for heating included in steam inputs
Wax	kg	641	this is heated to 70 deg C, assume energy required for heating included in steam inputs
Starch	kg	600	this is heated to 100 deg C, assume energy required for heating included in steam inputs
Cooling Water	Ml	10.6	mass allocation of monthly water, less process water requirements
Electricity	MWh	2.5	mass allocation
Outputs			
Product	tons	5	
Effluent	Ml	9.5	assume 10% evaporative loss of cooling water (in cooling circuit and once-through combined)
Steam condensate	see next sheet		

HI PHASE PROCESS	**PER BATCH**		
Process Inputs	**Units**	**Ave Value**	**Notes**
Rosin	tons	3	
Process water	tons	7.5	
Starch	kg	400	this is heated to 100 deg C
Steam	see next sheet		Assumed saturated steam. The nearest company generates 20 bar, but 5 bar is lost due to leaks.
Furmeric Acid	tons	0.333	
Electricity	MWh	5.5	mass allocation
Cooling Water	Ml	23.1	mass allocation of monthly water, less process water requirements
Outputs			
Product	tons	10.9	
Effluent	Ml	20.8	assume 10% evaporative loss of cooling water (in cooling circuit and once-through combined), need to add steam condensate
Steam condensate	see next sheet		

Process Inputs	**Units**	**Aquapel**	***Hi-phase/composite***	
			liquid rosin	**solid rosin**
Wax/rosin	kg	641	3000	3000
Starch	kg	600	400	400
Steam	MJ	2282	8116	18260
Process water	kl	4.3	7.5	7.5
Cooling water	kl	10600	23100	23100
Electricity	MWh	2.5	5.5	5.5
Outputs				
Product	tons	5	10.9	10.9
Effluent	kl	9500	20800	20800
Steam condensate	kl	0.8	3.0	6.7

Appendix 3: Water Consumption

WATER CONSUMPTION

Month	Tons of Products Produced per month				Volume (kL)	Cost (R)
	No. of Batches	Aquapel	Hi Phase Composite	No. of Batches		
Jan	*3*	15.00	196.20	18	310319	5557
Feb	*2*	10.00	185.30	17	358784	6422
Mar	*3*	15.00	196.20	18	461824	8267
Apr	*3*	15.00	218.00	20	608532	10893
May	*3*	15.00	218.00	20	500988	8968
Jun	*3*	15.00	218.00	20	437351	7829
Jul	*2*	10.00	174.40	16	539384	9655
Aug	*3*	15.00	218.00	20	438174	7843

	Ml per batch combined	per month Aquapel	hi phase	Ml per ton total	per month Aquapel	hi phase	Ml per batch Aquapel	hi phase		no. Batches per month
	15	44	266	1.5	22	288	7.3	16		21
	19	38	321	1.8	18	340	9.2	20		19
	22	66	396	2.2	33	429	11	24		21
	26	79	529	2.6	39	569	13	28		23
	22	65	436	2.2	32	469	11	23		23
	19	57	380	1.9	28	409	9.4	20		23
	30	60	479	2.9	29	510	15	32		18
	19	57	381	1.9	28	410	9.4	20		23
std dev	5	13	84	0.5	6	90	2	5		
mean	21	58	399	2	29	428	11	23		
CV	0.22	0.22	0.21	0.22	0.22	0.21	0.22	0.22		

Appendix 4: Electricity Consumption

ELECTRICITY CONSUMPTION

Month	Tons of Products Produced per month				Plant Consumption (kWh)	Cost (Rands)
	No. of Batches	Aquapel	Hi Phase Composite	No. of Batches		
Jan	*3*	15.00	196.20	18	111491	14486
Feb	*2*	10.00	185.30	17	110608	13372
Mar	*3*	15.00	196.20	18	111761	14826
Apr	*3*	15.00	218.00	20	113316	16786
May	*3*	15.00	218.00	20	112137	15300
Jun	*3*	15.00	218.00	20	112321	15532
Jul	*2*	10.00	174.40	16	90560	11416
Aug	*3*	15.00	218.00	20	112511	15771

	MWh per batch			MWh per ton			MWh per batch		
	combined	Aquapel	hi phase	total	Aquapel	hi phase	Aquapel	hi phase	
	5.3	16	96	0.53	7.92	104	2.64	5.75	
	5.8	12	99	0.57	5.66	105	2.83	6.17	
	5.3	16	96	0.53	7.94	104	2.65	5.77	
	4.9	15	99	0.49	7.30	106	2.43	5.30	
	4.9	15	98	0.48	7.22	105	2.41	5.25	
	4.9	15	98	0.48	7.23	105	2.41	5.25	
	5.0	10	80	0.49	4.91	86	2.46	5.35	
	4.9	15	98	0.48	7.24	105	2.41	5.26	
std dev	0.3	2	6	0	1	7	0.16	0.34	
mean	5	14	95	1	7	102	2.53	5.51	
CV	0.07	0.15	0.06	0.06	0.16	0.07	0.06	0.06	

STEAM USAGE CALCULATIONS

The enthalpy of saturated steam at 20 bar (absolute)			2797 kJ/kg
The enthalpy of water at 18 deg C and 1 atm			76 kJ/kg
Difference (energy required to generate steam)			2721 kJ/kg

24 hrs per day in hourly steam calc. (gives very low steam usages which do not agree well with per batch calc.)

		low estimate	high estimate	average	units
Daily steam requirments		1.84	4.87	3.36	tpd
		5007	13253	9130	MJ/day
		209	552	380	MJ/hr

Duration steam required:		low estimate	high estimate	average	units
Aquapel	2.25 hrs	469	1242	856	MJ
Hi-phase	2.30 hrs	480	1270	875	MJ
Melting rosin:					
liquid	8 hrs	1669	4418	3043	MJ
solid	48 hrs	10014	26506	18260	MJ
(2 days = 2 x 24 hour periods?)					
HI-phase totals:					
liquid	10 hrs	2149	5688	3918	MJ
solid	50 hrs	10494	27776	19135	MJ
Steam condensate:					
Aquapel	2.25 hrs	0.17	0.46	0.31	tons
Hi-phase	2.30 hrs	0.18	0.47	0.32	tons
Steam condensate factor		0.00036747			

OR **9 hrs per day (not 24 in hourly steam calc.)**

		low estimate	high estimate	average	
Daily steam requirments		1.84	4.87	3.36	tpd
		5007	13253	9130	MJ/day
		556	1473	1014	MJ/hr

Duration steam required:		low estimate	high estimate	average	
Aquapel	2.25 hrs	1252	3313	2282	MJ
Hi-phase	2.30 hrs	1280	3387	2333	MJ
Melting rosin:					
liquid	8 hrs	4451	11780	8116	MJ
solid	18 hrs	10014	26506	18260	MJ
(2 days = 2 x 9 hour periods?)					
HI-phase totals:					
liquid	10 hrs	5730	15167	10449	MJ
solid	20 hrs	11294	29892	20593	MJ
Steam condensate:					
Aquapel	2.25 hrs	0.46	1.22	0.84	tons
Hi-phase	2.30 hrs	0.47	1.24	0.86	tons

OR **steam per batch (one batch a day)**

Aquapel	low estimate	1.84	tpd
		5007	MJ/batch
		1001	MJ/ton
Hi-phase	high estimate	4.87	tpd
		13253	MJ/batch
		1216	MJ/ton

Appendix 6: Characterisation (Impact Assessment IMPACT 2002+)

Title:	**Comparing 1 ton 'Emulsion, produced by Aquapel process', 1 ton 'Emulsion, produced by Hi-phase/composite process using liquid rosin' and 1 ton 'Emulsion, produced by Hi-phase/composite process using solid rosin'**			
Method:	IMPACT 2002+ V2.03 / IMPACT 2002+			
Indicator:	Characterisation			
Skip categories:	Never			
Relative mode:	Non			
Impact category	Unit	Emulsion, produced by Aquapel process	Emulsion, produced by Hi-phase/composite process using liquid rosin	Emulsion, produced by Hi-phase/composite process using solid rosin
Carcinogens	kg C2H3Cl	13.226328	15.850462	12.624689
Non-Carcinogens	kg C2H3Cl	256.15934	263.03101	250.36005
Respiratory inorganics	kg PM2.5	2.9598754	3.443205	3.1862057
Ionizing radiation	Bq C-14	19852.08	18694.365	16668.795
Ozone layer depletion	kg CFC-11	5.65E-05	4.85E-05	4.76E-05
Respiratory organics	kg ethylene	0.24940202	0.2662222	0.20424375
Aquatic ecotoxicity	kg TEG wate	14102545	14104887	14095217
Terrestrial ecotoxicity	kg TEG soil	1022079.1	1013408.3	1010052.5
Terrestrial acid/nutri	kg SO2	87.427995	93.028685	88.869235
Land occupation	m2org.arable	247.35969	365.64899	78.559826
Aquatic acidification	kg SO2	26.342028	28.626939	27.437225
Aquatic eutrophication	kg PO4 P-lim	6.5203272	6.6398511	6.4618627
Global warming	kg CO2	2175.5043	2414.3056	2282.5854
Non-renewable energy	MJ primary	35159.61	31133.197	29469.207
Mineral extraction	MJ surplus	4.8711007	4.9392235	4.8750915

Appendix 7: Normalisation (Impact Assessment IMPACT 2002+)

Title:	**Comparing 1 ton 'Emulsion, produced by Aquapel process', 1 ton 'Emulsion, produced by Hi-phase/composite process using liquid rosin' and 1 ton 'Emulsion, produced by Hi-phase/composite process using solid rosin'**		
Method:	IMPACT 2002+ V2.03 / IMPACT 2002+		
Indicator:	Normalisation		
Per impact category:	Yes		
Skip categories:	Never		
Relative mode:	Non		
Impact category	Unit	Emulsion, produced by Aquapel process	Emulsion, produced by Hi-phase/composite process using liquid rosin	Emulsion, produced by Hi-phase/composite process using solid rosin
Carcinogens		0.005221754	0.006257763	0.004984227
Non-Carcinogens		0.10113171	0.10384464	0.09884215
Respiratory inorganics		0.2921397	0.33984434	0.3144785
Ionizing radiation		0.00058782	0.00055354	0.000493563
Ozone layer depletion		8.37E-06	7.18E-06	7.04E-06
Respiratory organics		7.49E-05	8.00E-05	6.13E-05
Aquatic ecotoxicity		0.051680185	0.051688771	0.051653331
Terrestrial ecotoxicity		0.59017914	0.58517235	0.58323463
Terrestrial acid/nutri		0.006637533	0.007062738	0.006746952
Land occupation		0.019682411	0.02909469	0.006251005
Aquatic acidification		-	-	-
Aquatic eutrophication		-	-	-
Global warming		0.21972594	0.24384487	0.23054113
Non-renewable energy		0.23135023	0.20485643	0.19390738
Mineral extraction		3.21E-05	3.25E-05	3.21E-05

Appendix 8: Damage Assessment (Impact Assessment Method IMPACT 2002+)

Title:	**Comparing 1 ton 'Emulsion, produced by Aquapel process', 1 ton 'Emulsion, produced by Hi-phase/composite process using liquid rosin' and 1 ton 'Emulsion, produced by Hi-phase/composite process using solid rosin'**			
Method:	IMPACT 2002+ V2.03 / IMPACT 2002+			
Indicator:	Damage assessment			
Per impact category:	No			
Skip categories:	Never			
Relative mode:	Non			
Damage category	Unit	Emulsion, produced by Aquapel process	Emulsion, produced by Hi-phase/composite process using liquid rosin	Emulsion, produced by Hi-phase/composite process using solid rosin
Human Health	DALY	0.002830952	0.003195655	0.002970687
Ecosystem Quality	PDF*m2*yr	9153.1407	9219.4322	8875.1496
Climate Change	kg CO2	2175.5043	2414.3056	2282.5854
Resources	MJ primary	35164.481	31138.136	29474.082

Appendix 9: Inventory All Compartments (Impact Assessment IMPACT 2002+)

Title	Comparing 1 ton 'Emulsion, produced by Aquapel process', 1 ton 'Emulsion, produced by Hi-phase/composite process using liquid rosin' and 1 ton 'Emulsion, produced by Hi-phase/composite process using solid rosin'
Method	IMPACT 2002+ V2.03 / IMPACT 2002+
Compartment	All compartments
Per sub-compartment	No
Default units	No
Indicator	Inventory
Relative mode	Non

No	Substance	Compartment	Unit	Emulsion, produced by Aquapel process	Emulsion, produced by Hi-phase/composite process using liquid rosin	Emulsion, produced by Hi-phase/composite process using solid rosin
1	Aluminium, 24% in bauxite, 11% in crude ore, in ground	Raw	kg	2.0151527	2.0355421	2.0217058
2	Anhydrite, in ground	Raw	mg	2.7821026	5.0129012	6.8978998
3	Barite, 15% in crude ore, in ground	Raw	g	45.621469	67.927538	45.84548
4	Basalt, in ground	Raw	mg	47.600929	84.751694	389.47294
5	Borax, in ground	Raw	mg	3.2584463	3.352603	3.1705161
6	Calcite, in ground	Raw	kg	5.7371409	10.437249	5.3000614
7	Carbon dioxide, in air	Raw	kg	264.17657	1274.5128	119.28482
8	Chromium, 25.5 in chromite, 11.6% in crude ore, in ground	Raw	g	3.1891548	6.8519268	2.987031
9	Chrysotile, in ground	Raw	mg	63.041549	309.62953	63.290955
10	Cinnabar, in ground	Raw	mg	66.227346	88.817992	66.169807
11	Clay, bentonite, in ground	Raw	g	19.13178	15.931907	14.251608
12	Clay, unspecified, in ground	Raw	kg	1.3873808	1.5830712	1.3916407
13	Coal, brown, in ground	Raw	kg	13.173923	15.814107	10.915319
14	Coal, hard, unspecified, in ground	Raw	ton	1.259785	1.4388477	1.3685947
15	Cobalt, in ground	Raw	µg	518.32582	615.50099	412.92588
16	Colemanite, in ground	Raw	mg	26.308642	25.432223	22.787479
17	Copper, 0.99% in sulfide, Cu 0.36% and Mo 8.2E-3% in crude ore, in grou	Raw	mg	13.683085	18.787255	22.726656
18	Copper, 1.18% in sulfide, Cu 0.39% and Mo 8.2E-3% in crude ore, in grou	Raw	mg	75.519668	103.38775	119.12096
19	Copper, 1.42% in sulfide, Cu 0.81% and Mo 8.2E-3% in crude ore, in grou	Raw	mg	20.005394	27.387724	31.555559
20	Copper, 2.19% in sulfide, Cu 1.83% and Mo 8.2E-3% in crude ore, in grou	Raw	mg	99.365974	136.03381	156.73651
21	Diatomite, in ground	Raw	µg	1.191149	1.1439039	1.0457315
22	Dolomite, in ground	Raw	mg	79.479459	126.65483	85.901802
23	Energy, gross calorific value, in biomass	Raw	GJ	3.0191781	14.121123	1.3389431
24	Energy, kinetic, flow, in wind	Raw	MJ	9.7566241	11.621881	7.9816677
25	Energy, potential, stock, in barrage water	Raw	MJ	624.84525	570.0328	527.78849
26	Energy, solar	Raw	kJ	287.74405	209.55131	157.48354
27	Feldspar, in ground	Raw	µg	1.4418692	2.4732989	12.500066
28	Fluorine, 4.5% in apatite, 1% in crude ore, in ground	Raw	mg	50.041449	49.9602	43.260205
29	Fluorine, 4.5% in apatite, 3% in crude ore, in ground	Raw	g	53.893362	16.576889	16.495883
30	Fluorspar, 92%, in ground	Raw	g	5.1142943	4.9621243	4.4279668
31	Gas, mine, off-gas, process, coal mining/m3	Raw	m3	5.0922167	5.8149088	5.5163986
32	Gas, natural, in ground	Raw	m3	35.205141	14.105109	11.658599
33	Granite, in ground	Raw	mg	0.023649079	1.6662629	0.07550293
34	Gravel, in ground	Raw	kg	2.6231903	217.9911	2.6367721
35	Gypsum, in ground	Raw	mg	274.83811	353.84333	274.15701
36	Iron, 46% in ore, 25% in crude ore, in ground	Raw	g	366.42601	153.57631	136.98787
37	Kaolinite, 24% in crude ore, in ground	Raw	g	11.098963	12.677947	241.18981
38	Kieserite, 25% in crude ore, in ground	Raw	kg	2.68E-05	1.099847	2.90E-05
39	Lead, 5%, in sulfide, Pb 2.97% and Zn 5.34% in crude ore, in ground	Raw	mg	5.1835372	7.7631229	22.638433
40	Magnesite, 60% in crude ore, in ground	Raw	g	11.892967	4.8841826	4.5967725
41	Magnesium, 0.13% in water	Raw	µg	0.19433936	0.33703425	1.3916868
42	Manganese, 35.7% in sedimentary deposit, 14.2% in crude ore, in ground	Raw	mg	13.709974	147.7175	27.344616
43	Molybdenum, 0.010% in sulfide, Mo 8.2E-3% and Cu 1.83% in crude ore,	Raw	mg	1.8465884	2.52801	2.9127013
44	Molybdenum, 0.014% in sulfide, Mo 8.2E-3% and Cu 0.81% in crude ore,	Raw	µg	262.77234	359.73989	414.48394
45	Molybdenum, 0.022% in sulfide, Mo 8.2E-3% and Cu 0.36% in crude ore,	Raw	mg	5.320492	59.811991	10.73927
46	Molybdenum, 0.025% in sulfide, Mo 8.2E-3% and Cu 0.39% in crude ore,	Raw	mg	0.9641932	1.319996	1.5208519
47	Molybdenum, 0.11% in sulfide, Mo 4.1E-2% and Cu 0.36% in crude ore, it	Raw	mg	10.737958	120.71407	21.674579
48	Nickel, 1.13% in sulfide, Ni 0.76% and Cu 0.76% in crude ore, in ground	Raw	g	1.1806219	0.58291068	0.56662334
49	Nickel, 1.98% in silicates, 1.04% in crude ore, in ground	Raw	g	2.5522564	3.9657908	2.537855
50	Occupation, arable, non-irrigated	Raw	m2a	202.11882	62.114897	61.828903
51	Occupation, construction site	Raw	m2a	2.4387969	0.83016585	0.8239182
52	Occupation, dump site	Raw	m2a	2.8137426	3.179157	3.0117806
53	Occupation, dump site, benthos	Raw	mm2a	7.0139443	10.547403	35.766677
54	Occupation, forest, intensive	Raw	m2a	0.13868003	2307.6606	0.14942175
55	Occupation, forest, intensive, normal	Raw	m2a	38.225763	265.41357	38.20311
56	Occupation, industrial area	Raw	cm2a	164.39096	186.15396	134.18643
57	Occupation, industrial area, benthos	Raw	mm2a	0.062511505	0.093875948	0.31929996
58	Occupation, industrial area, built up	Raw	m2a	38.849474	11.883592	11.881051
59	Occupation, industrial area, vegetation	Raw	mm2a	32.374349	48.223956	154.1358
60	Occupation, mineral extraction site	Raw	m2a	2.6493348	3.0204743	2.8669164
61	Occupation, permanent crop, fruit, intensive	Raw	cm2a	20.478054	8.0390822	7.8695131
62	Occupation, shrub land, sclerophyllous	Raw	m2a	0.10714556	0.11713529	0.11073601
63	Occupation, traffic area, rail embankment	Raw	mm2a	23.418177	38.657236	119.55032
64	Occupation, traffic area, rail network	Raw	mm2a	25.894844	42.745818	132.19457
65	Occupation, traffic area, road embankment	Raw	m2a	0.37555346	40.581106	0.37551896
66	Occupation, traffic area, road network	Raw	mm2a	84.212214	111.77798	185.20646
67	Occupation, urban, discontinuously built	Raw	mm2a	0.003881119	0.005942902	0.01811496
68	Occupation, water bodies, artificial	Raw	m2a	4.2608397	4.5080301	4.1976054
69	Occupation, water courses, artificial	Raw	m2a	0.10073196	0.069335332	0.053063687
70	Oil, crude, in ground	Raw	kg	166.50842	24.269043	24.722126

Appendix 9: continued

Title: Comparing 1 ton 'Emulsion, produced by Aquapel process', 1 ton 'Emulsion, produced by Hi-phase/composite process using liquid resin' and 1 ton 'Emulsion, produced by Hi-phase/composite process using solid rosin'
Method: IMPACT 2002+ V2.03 / IMPACT 2002+
Compartment: All compartments
Per sub-compartment: No
Default units: No
Indicator: Inventory
Relative mode: Non

71	Oleorosin	Raw	kg	x	x		344.0367
72	Olivine, in ground	Raw	mg		0.85604223	1.5452682	2.1912194
73	Pd, Pd 2.0E-4%, Pt 4.8E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in or	Raw	µg		32.709283	40.180777	32.340798
74	Pd, Pd 7.3E-4%, Pt 2.5E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in c	Raw	µg		78.609971	96.566157	77.724393
75	Peat, in ground	Raw	g		0.31150966	3.510459	0.3331828
76	Phosphorus, 18% in apatite, 12% in crude ore, in ground	Raw	g		214.66048	66.027298	65.707371
77	Phosphorus, 18% in apatite, 4% in crude ore, in ground	Raw	mg		200.1658	199.84081	173.04083
78	Pt, Pt 2.5E-4%, Pd 7.3E-4%, Rh 2.0E-5%, Ni 2.3E+0%, Cu 3.2E+0% in o	Raw	ng		753.44396	925.44162	745.25693
79	Pt, Pt 4.8E-4%, Pd 2.0E-4%, Rh 2.4E-5%, Ni 3.7E-2%, Cu 5.2E-2% in or	Raw	µg		2.7009859	3.3175722	2.6716367
80	Rh, Rh 2.0E-5%, Pt 2.5E-4%, Pd 7.3E-4%, Ni 2.3E+0%, Cu 3.2E+0% in c	Raw	ng		747.792	918.60141	739.36683
81	Rh, Rh 2.4E-5%, Pt 4.8E-4%, Pd 2.0E-4%, Ni 3.7E-2%, Cu 5.2E-2% in or	Raw	µg		2.3421803	2.8771772	2.3157915
82	Rhenium, in crude ore, in ground	Raw	µg		1.1689256	2.219025	1.0988177
83	Rutile, in ground	Raw	µg		1.4401479	2.4700404	12.494356
84	Sand, unspecified, in ground	Raw	mg		27.748964	49.430839	65.942189
85	Shale, in ground	Raw	mg		7.8618187	14.16759	19.542165
86	Silver, 0.01% in crude ore, in ground	Raw	ng		37.103229	59.099003	171.89038
87	Sodium chloride, in ground	Raw	kg		17.701954	31.254507	17.702406
88	Sodium sulphate, various forms, in ground	Raw	mg		397.84474	620.19291	349.94471
89	Stibnite, in ground	Raw	ng		123.78607	118.87629	108.67402
90	Sulfur, in ground	Raw	mg		16.86738	31.749476	131.45206
91	Sylvite, 25 % in sylvinite, in ground	Raw	g		12.075751	5.1945494	4.5543383
92	Talc, in ground	Raw	g		1.17777	612.35607	1.2798718
93	Tin, 79% in cassiterite, 0.1% in crude ore, in ground	Raw	µg		508.99223	604.0407	823.19161
94	TiO2, 45-60% in Ilmenite, in ground	Raw	g		13.642653	13.787618	13.31072
95	Transformation, from arable	Raw	mm2		767.34918	775.11102	769.90437
96	Transformation, from arable, non-irrigated	Raw	m2		332.68227	102.3013	101.77237
97	Transformation, from arable, non-irrigated, fallow	Raw	mm2		244.54116	247.01084	245.33195
98	Transformation, from dump site, inert material landfill	Raw	mm2		7.914619	88.558546	8.381377
99	Transformation, from dump site, residual material landfill	Raw	cm2		189.08182	205.99344	196.31379
100	Transformation, from dump site, sanitary landfill	Raw	mm2		6.1485817	235.16427	6.0048165
101	Transformation, from dump site, slag compartment	Raw	cm2		24.766133	24.710333	24.700262
102	Transformation, from forest	Raw	mm2		51.314617	95.015865	111.67346
103	Transformation, from forest, extensive	Raw	m2		0.2581492	17.589434	0.25805041
104	Transformation, from industrial area	Raw	mm2		264.7232	249.11801	223.81166
105	Transformation, from industrial area, benthos	Raw	mm2		0.000567844	0.00085921	0.003020477
106	Transformation, from industrial area, built up	Raw	mm2		0.071463376	0.071346957	0.061779205
107	Transformation, from industrial area, vegetation	Raw	mm2		0.12190811	0.12170951	0.10538804
108	Transformation, from mineral extraction site	Raw	cm2		22.025606	47.638471	18.750748
109	Transformation, from pasture and meadow	Raw	dm2		43.907516	15.137766	14.999634
110	Transformation, from pasture and meadow, intensive	Raw	dm2		26.841422	8.2538038	8.2111801
111	Transformation, from sea and ocean	Raw	mm2		7.041727	10.581026	35.818521
112	Transformation, from shrub land, sclerophyllous	Raw	cm2		220.27854	238.27023	224.46974
113	Transformation, from unknown	Raw	dm2		7.0024651	14.925699	7.2803233
114	Transformation, to arable	Raw	cm2		12.444037	13.618952	11.496916
115	Transformation, to arable, non-irrigated	Raw	m2		333.34865	102.50554	101.97618
116	Transformation, to arable, non-irrigated, fallow	Raw	mm2		268.5706	271.95045	269.43825
117	Transformation, to dump site	Raw	cm2		187.65754	214.16211	202.92334
118	Transformation, to dump site, benthos	Raw	mm2		7.0139443	10.547403	35.766677
119	Transformation, to dump site, inert material landfill	Raw	mm2		7.914619	88.558546	8.381377
120	Transformation, to dump site, residual material landfill	Raw	cm2		189.08182	205.99344	196.31379
121	Transformation, to dump site, sanitary landfill	Raw	mm2		6.1485817	235.16427	6.0048165
122	Transformation, to dump site, slag compartment	Raw	cm2		24.766133	24.710333	24.700262
123	Transformation, to forest	Raw	cm2		217.46028	264.08418	224.62259
124	Transformation, to forest, intensive	Raw	m2		0.000923801	15.38077	0.000995359
125	Transformation, to forest, intensive, normal	Raw	dm2		25.448778	193.6379	25.43422
126	Transformation, to heterogeneous, agricultural	Raw	mm2		0.61655985	0.92177592	2.9821159
127	Transformation, to industrial area	Raw	mm2		181.75305	203.24804	151.28084
128	Transformation, to industrial area, benthos	Raw	mm2		0.027774927	0.033591636	0.051828376
129	Transformation, to industrial area, built up	Raw	cm2		158.35645	50.523084	50.442173
130	Transformation, to industrial area, vegetation	Raw	mm2		0.57359683	0.88546299	3.1788989
131	Transformation, to mineral extraction site	Raw	cm2		245.30831	870.99865	260.46049
132	Transformation, to pasture and meadow	Raw	mm2		329.5345	101.89715	101.82305
133	Transformation, to permanent crop, fruit, intensive	Raw	mm2		40.042756	15.185288	14.894498
134	Transformation, to sea and ocean	Raw	mm2		0.000567844	0.00085921	0.003020477
135	Transformation, to shrub land, sclerophyllous	Raw	cm2		213.98859	233.941	221.15792
136	Transformation, to traffic area, rail embankment	Raw	mm2		0.054492647	0.089953385	0.27818358
137	Transformation, to traffic area, rail network	Raw	mm2		0.059896152	0.09887304	0.30577006
138	Transformation, to traffic area, road embankment	Raw	dm2		0.25061168	27.207581	0.25058969
139	Transformation, to traffic area, road network	Raw	mm2		0.93441755	1.2604191	2.068694
140	Transformation, to unknown	Raw	mm2		289.66568	278.56403	247.5831

Appendix 9: continued

Title: Comparing 1 ton 'Emulsion, produced by Aquapel process', 1 ton 'Emulsion, produced by Hi-phase/composite process using liquid resin' and 1 ton 'Emulsion, produced by Hi-phase/composite process using solid rosin'
Method: IMPACT 2002+ V2.03 / IMPACT 2002+
Compartment: All compartments
Per sub-compartment: No
Default units: No
Indicator: Inventory
Relative mode: Non

141	Transformation, to urban, discontinuously built	Raw	mm2	7.73E-05	0.000118378	0.000360837
142	Transformation, to water bodies, artificial	Raw	cm2	279.04249	416.52904	274.93136
143	Transformation, to water courses, artificial	Raw	cm2	12.468253	8.5819378	6.5670387
144	Ulexite, in ground	Raw	µg	3.1575171	5.0287245	14.816382
145	Uranium, in ground	Raw	g	3.432927	3.2404505	2.8908367
146	Vermiculite, in ground	Raw	µg	6.7338553	12.75708	22.383764
147	Volume occupied, final repository for low-active radioactive waste	Raw	cm3	6.7332938	6.3261264	5.615004
148	Volume occupied, final repository for radioactive waste	Raw	cm3	1.7491982	1.6808919	1.4995057
149	Volume occupied, reservoir	Raw	m3y	20.849123	20.139887	19.097985
150	Volume occupied, underground deposit	Raw	cm3	155.51881	200.32148	154.79159
151	Water, cooling, unspecified natural origin/m3	Raw	m3	9.1680987	17.374126	5.886061
152	Water, lake	Raw	m3	435.32149	435.10943	435.10573
153	Water, river	Raw	m3	1092.8585	1092.3872	1092.1632
154	Water, salt, ocean	Raw	l	234.85555	218.61701	195.43095
155	Water, salt, sole	Raw	l	20.337269	16.860293	17.085636
156	Water, turbine use, unspecified natural origin	Raw	m3	1992.9967	1706.1589	1501.4333
157	Water, unspecified natural origin/m3	Raw	m3	1.5054667	13.164159	0.70328663
158	Water, well, in ground	Raw	m3	871.05736	870.72268	870.64547
159	Wood, hard, standing	Raw	l	46.77107	478.24571	46.709706
160	Wood, soft, standing	Raw	l	0.58916989	793.30134	0.4988347
161	Wood, unspecified, standing/m3	Raw	mm3	1.4136645	2.8032567	17.028314
162	Zinc 9%, in sulfide, Zn 5.34% and Pb 2.97% in crude ore, in ground	Raw	g	1.2543823	1.4844205	1.4434335
163	Acenaphthene	Air	ng	81.987459	103.10861	70.62708
164	Acetaldehyde	Air	mg	55.942708	63.549745	15.005491
165	Acetic acid	Air	mg	394.38139	166.73645	336.91479
166	Acetone	Air	mg	59.968901	26.377127	18.628508
167	Acrolein	Air	µg	41.085904	57.090443	50.91135
168	Actinides, radioactive, unspecified	Air	µBq	79.632374	79.480856	71.541036
169	Aerosols, radioactive, unspecified	Air	Bq	1.3793858	1.3889332	1.2412705
170	Aldehydes, unspecified	Air	mg	2.8887375	2.8807521	4.3068293
171	Aluminum	Air	g	227.15294	289.38313	272.23747
172	Ammonia	Air	g	940.8164	735.56705	732.69633
173	Ammonium carbonate	Air	µg	0.72329726	82.508141	8.7953459
174	Antimony	Air	mg	1.5942872	6.3249511	5.4569156
175	Antimony-124	Air	µBq	22.578046	9.225716	8.0899255
176	Antimony-125	Air	µBq	235.62088	96.278099	84.42517
177	Argon-41	Air	Bq	219.18037	232.42151	163.03471
178	Arsenic	Air	mg	32.680298	105.22038	94.569068
179	Barium	Air	mg	154.90111	528.35269	463.32888
180	Barium-140	Air	mBq	15.326788	6.262747	5.4917317
181	Benzaldehyde	Air	µg	17.683303	25.53434	23.611117
182	Benzene	Air	g	5.6824966	8.1643896	7.0759958
183	Benzene, ethyl-	Air	mg	39.135099	60.155182	36.69663
184	Benzene, hexachloro-	Air	µg	356.16659	350.44099	350.26652
185	Benzene, pentachloro-	Air	µg	875.76758	873.77591	873.53576
186	Benzo(a)pyrene	Air	mg	1.4594953	2.0071821	1.2035203
187	Beryllium	Air	mg	0.90958075	4.6181889	4.0017976
188	Boron	Air	g	4.2328523	5.8408402	5.3271107
189	Bromine	Air	g	1.0061494	1.1124965	1.0208393
190	Butadiene	Air	ng	5.8067331	7.1330686	5.7414456
191	Butane	Air	g	3.2236133	2.3642623	2.2945591
192	Butene	Air	mg	38.960898	36.190828	36.55958
193	Cadmium	Air	mg	12.265766	9.3656157	7.7162721
194	Calcium	Air	g	12.515487	20.295093	15.570216
195	Carbon-14	Air	kBq	6.1408722	5.7258893	5.1015914
196	Carbon dioxide, biogenic	Air	kg	448.63553	1056.8083	447.37176
197	Carbon dioxide, fossil	Air	ton	2.0603432	2.312718	2.1841692
198	Carbon disulfide	Air	mg	10.926654	10.714692	8.1329145
199	Carbon monoxide, biogenic	Air	kg	2.0306121	2.063681	2.029707
200	Carbon monoxide, fossil	Air	kg	0.4534497	1.0032186	0.73747169
201	Cerium-141	Air	mBq	3.7155601	1.5182316	1.33132
202	Cesium-134	Air	µBq	177.95144	72.713529	63.761666
203	Cesium-137	Air	mBq	3.1545004	1.2889745	1.1302871
204	Chlorine	Air	g	0.95236647	1.3884942	0.95027133
205	Chloroform	Air	µg	53.305921	41.582371	35.647371
206	Chromium	Air	mg	31.682917	99.268943	83.346042
207	Chromium-51	Air	µBq	238.09243	97.288009	85.310749
208	Chromium VI	Air	mg	2.7460312	10.99156	9.514723
209	Cobalt	Air	mg	16.975849	18.2909	15.388793
210	Cobalt-58	Air	µBq	331.55355	135.47757	118.79874

Appendix 9: continued

Title: Comparing 1 ton 'Emulsion, produced by Aquapel process', 1 ton 'Emulsion, produced by Hi-phase/composite process using liquid resin' and 1 ton 'Emulsion, produced by Hi-phase/composite process using solid rosin'
Method: IMPACT 2002+ V2.03 / IMPACT 2002+
Compartment: All compartments
Per sub-compartment: No
Default units: No
Indicator: Inventory
Relative mode: Non

211	Cobalt-60	Air	mBq	2.9289671	1.1968183	1.0494764
212	Copper	Air	mg	287.69957	203.15415	167.7772
213	Cumene	Air	mg	5.1049707	9.6089465	64.241563
214	Cyanide	Air	g	3.1429572	3.1395319	3.1393366
215	Dinitrogen monoxide	Air	g	535.29156	423.59469	417.69656
216	Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	Air	µg	2.8735652	4.3312788	2.9210177
217	Ethane	Air	g	69.958955	70.859079	69.621383
218	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	mg	43.122054	102.3837	56.215492
219	Ethane, 1,2-dichloro-	Air	mg	2.8707726	2.6823659	3.6173446
220	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	mg	1.6418805	1.5193071	1.3670565
221	Ethane, hexafluoro-, HFC-116	Air	mg	2.1902755	2.5032946	2.381217
222	Ethanol	Air	mg	109.44074	40.671808	28.961303
223	Ethene	Air	g	22.756012	31.565491	30.137137
224	Ethene, chloro-	Air	mg	0.57264192	1.0237885	1.2978783
225	Ethylene diamine	Air	µg	1.0293921	1.175826	1.1190451
226	Ethylene oxide	Air	mg	0.069119892	6.0089361	0.82619317
227	Ethyne	Air	g	0.33838601	1.8093692	1.5656426
228	Fluorine	Air	mg	0.66757644	35.649298	0.63048906
229	Fluosilicic acid	Air	mg	2.5599042	2.9257445	2.7830646
230	Formaldehyde	Air	g	1.7043187	1.7006467	1.5023218
231	Heat, waste	Air	GJ	22.579804	25.84543	23.611404
232	Helium	Air	mg	100.05694	80.784284	80.018853
233	Heptane	Air	mg	386.55248	356.51882	362.58943
234	Hexane	Air	mg	966.01306	974.66715	891.00032
235	Hydrocarbons, aliphatic, alkanes, cyclic	Air	µg	7.786362	15.80559	18.111542
236	Hydrocarbons, aliphatic, alkanes, unspecified	Air	g	5.2334886	7.0809671	5.9019284
237	Hydrocarbons, aliphatic, unsaturated	Air	g	4.4133506	8.2020558	5.6002343
238	Hydrocarbons, aromatic	Air	mg	499.04262	535.86787	323.73014
239	Hydrocarbons, chlorinated	Air	mg	1.8854744	2.8322831	2.2257131
240	Hydrogen	Air	g	5.6045034	482.64168	5.6191372
241	Hydrogen-3, Tritium	Air	kBq	34.775814	34.340482	30.739156
242	Hydrogen chloride	Air	g	49.251707	169.18896	148.45612
243	Hydrogen fluoride	Air	g	22.243636	26.664867	25.14733
244	Hydrogen sulfide	Air	g	0.81938677	52.576295	0.23520137
245	Iodine	Air	mg	567.77957	621.9338	591.18981
246	Iodine-129	Air	Bq	5.8990479	5.7550351	5.130783
247	Iodine-131	Air	Bq	84.079251	91.071693	63.672884
248	Iodine-133	Air	mBq	18.326069	7.4882966	6.5664021
249	Iron	Air	g	3.6610996	16.619146	14.462398
250	Isocyanic acid	Air	µg	0.46853678	0.75736742	2.249634
251	Krypton-85	Air	Bq	696.09594	730.97717	513.54091
252	Krypton-85m	Air	Bq	231.10323	101.64001	87.069814
253	Krypton-87	Air	Bq	56.988561	28.754492	23.653861
254	Krypton-88	Air	Bq	71.053273	33.310924	27.989149
255	Krypton-89	Air	Bq	28.123362	11.847746	10.287512
256	Lanthanum-140	Air	mBq	1.3099203	0.53525237	0.46935671
257	Lead	Air	mg	94.296279	342.03027	265.4968
258	Lead-210	Air	Bq	55.19959	192.15633	166.9103
259	m-Xylene	Air	mg	1.5405536	85.599029	1.414323
260	Magnesium	Air	g	3.8078509	15.207915	13.107791
261	Manganese	Air	mg	27.036307	212.27038	80.837375
262	Manganese-54	Air	µBq	121.92969	49.822233	43.688549
263	Mercury	Air	mg	55.292761	70.133654	61.376892
264	Methane, biogenic	Air	kg	1.3457056	1.4100345	1.3432799
265	Methane, bromochlorodifluoro-, Halon 1211	Air	mg	1.7199729	0.61220711	0.50245274
266	Methane, bromotrifluoro-, Halon 1301	Air	mg	1.0865105	0.97713761	0.98874219
267	Methane, chlorodifluoro-, HCFC-22	Air	mg	6.35381	2.6261068	2.0865573
268	Methane, dichloro-, HCC-30	Air	µg	1.599609	1.248361	1.0763404
269	Methane, dichlorodifluoro-, CFC-12	Air	µg	46.481113	73.654709	41.678798
270	Methane, dichlorofluoro-, HCFC-21	Air	pg	0.026892701	0.046698338	0.10789502
271	Methane, fossil	Air	kg	3.6831459	4.0838595	3.860462
272	Methane, monochloro-, R-40	Air	pg	0.85448897	1.3519665	4.7294965
273	Methane, tetrachloro-, CFC-10	Air	mg	42.822717	43.069604	42.79621
274	Methane, tetrafluoro-, FC-14	Air	mg	19.71248	22.529652	21.430954
275	Methane, trichlorofluoro-, CFC-11	Air	pg	0.043658711	0.075811958	0.1751581
276	Methane, trifluoro-, HFC-23	Air	pg	8.5567061	14.858469	34.329367
277	Methanol	Air	mg	261.98458	511.3069	229.28601
278	Molybdenum	Air	mg	11.4062	21.763306	18.808461
279	Monoethanolamine	Air	g	0.000504437	3.5784854	0.000462403
280	Nickel	Air	mg	245.27983	147.03463	313.81555

Appendix 9: continued

Title: Comparing 1 ton 'Emulsion, produced by Aquapel process', 1 ton 'Emulsion, produced by Hi-phase/composite process using liquid resin' and 1 ton 'Emulsion, produced by Hi-phase/composite process using solid rosin'
Method: IMPACT 2002+ V2.03 / IMPACT 2002+
Compartment: All compartments
Per sub-compartment: No
Default units: No
Indicator: Inventory
Relative mode: Non

281	Niobium-95	Air	µBq	14.474116	5.9143329	5.1862113
282	Nitrate	Air	mg	9.7229316	11.106796	10.569895
283	Nitrogen oxides	Air	kg	10.205585	11.502978	10.86524
284	NMVOC, non-methane volatile organic compounds, unspecified origin	Air	g	311.25092	317.35364	221.30495
285	Noble gases, radioactive, unspecified	Air	kBq	56698.497	55316.164	49317.079
286	Ozone	Air	g	23.458572	23.639434	23.174369
287	PAH, polycyclic aromatic hydrocarbons	Air	mg	50.514866	54.745799	56.029875
288	Paraffins	Air	ng	0.17976878	0.33309213	1.61355
289	Particulates, < 2.5 um	Air	g	193.44491	415.62128	288.24107
290	Particulates, > 10 um	Air	g	596.12606	718.59524	669.82274
291	Particulates, > 2.5 um, and < 10um	Air	g	75.151475	206.64656	180.84705
292	Pentane	Air	g	6.2140714	5.249611	5.0825953
293	Phenol	Air	mg	0.9034053	1.1649744	1.0277841
294	Phenol, pentachloro-	Air	µg	569.98477	638.5019	468.49601
295	Phosphorus	Air	g	3.0319316	3.4247373	3.1835333
296	Platinum	Air	ng	9.1470147	3.8528647	3.2692743
297	Plutonium-238	Air	nBq	804.7256	785.07993	699.92184
298	Plutonium-alpha	Air	µBq	1.8447312	1.799696	1.6044819
299	Polonium-210	Air	Bq	97.858453	349.04418	303.12924
300	Polychlorinated biphenyls	Air	µg	10.391345	3.5435191	3.3716666
301	Potassium	Air	g	1.2801171	21.403734	4.3444236
302	Potassium-40	Air	Bq	29.130444	69.678792	62.012392
303	Propanal	Air	µg	17.683303	25.53434	23.611117
304	Propane	Air	g	4.9670764	6.5855726	5.9506961
305	Propene	Air	g	0.71627755	2.1930839	1.9582663
306	Propionic acid	Air	mg	21.692165	7.6040281	6.2797196
307	Propylene oxide	Air	µg	59.814722	67.667651	58.89378
308	Protactinium-234	Air	mBq	840.68633	793.51798	707.77388
309	Radioactive species, other beta emitters	Air	Bq	1.9210298	1.8455825	1.6849155
310	Radium-226	Air	Bq	43.291528	75.700502	66.430512
311	Radium-228	Air	Bq	46.060504	237.42905	205.55751
312	Radon-220	Air	Bq	0.67614516	3.6180471	3.130908
313	Radon-222	Air	kBq	111590.17	105330.76	93949.998
314	Ruthenium-103	Air	µBq	3.1800581	1.2994177	1.1394446
315	Scandium	Air	mg	0.85246036	4.5588774	3.9451311
316	Selenium	Air	mg	138.85688	168.41674	161.15202
317	Silicon	Air	g	21.58932	68.053094	60.348692
318	Silicon tetrafluoride	Air	µg	1.5133421	1.5108767	1.3082652
319	Silver	Air	ng	162.8913	101.22804	98.175356
320	Silver-110	Air	µBq	31.51681	12.878224	11.292768
321	Sodium	Air	g	1.3501787	3.9355001	2.6971296
322	Sodium chlorate	Air	mg	0.097467114	211.69025	0.083764816
323	Sodium dichromate	Air	mg	4.7190084	8.2927073	4.7171395
324	Sodium formate	Air	µg	25.910569	30.524278	27.862954
325	Strontium	Air	mg	140.55137	700.80694	606.4762
326	Styrene	Air	µg	6.0353306	6.838081	4.7463584
327	Sulfate	Air	g	45.640588	78.666377	43.518157
328	Sulfur dioxide	Air	kg	17.348248	18.898719	18.28211
329	Sulfur hexafluoride	Air	mg	150.71551	154.79343	147.45498
330	t-Butyl methyl ether	Air	mg	0.22529012	7.2828535	0.20006159
331	Thallium	Air	mg	1.17193	5.8258623	5.050253
332	Thorium	Air	mg	1.2851926	6.8745259	5.9489115
333	Thorium-228	Air	Bq	4.8593087	21.118208	18.32506
334	Thorium-230	Air	Bq	5.26283	3.6017568	3.2806364
335	Thorium-232	Air	Bq	4.1770856	14.584288	12.700059
336	Thorium-234	Air	mBq	840.89648	793.71832	707.95603
337	Tin	Air	mg	5.5179932	7.4115553	7.0561499
338	Titanium	Air	g	0.28967226	1.4046167	1.219968
339	Toluene	Air	g	3.0314174	3.6588849	3.2832567
340	Uranium	Air	mg	1.7108992	9.1537449	7.9212803
341	Uranium-234	Air	Bq	11.956499	9.9198645	8.9160367
342	Uranium-235	Air	mBq	476.38892	449.66019	401.07186
343	Uranium-238	Air	Bq	22.253787	49.94118	43.640434
344	Uranium alpha	Air	Bq	45.831112	43.255881	38.577238
345	Vanadium	Air	mg	836.07438	308.24706	248.28156
346	water	Air	g	332.11461	379.37462	361.04498
347	Xenon-131m	Air	Bq	290.9396	141.90305	117.86292
348	Xenon-133	Air	kBq	10.392558	4.8969021	4.108425
349	Xenon-133m	Air	Bq	15.957746	11.371154	8.5868618
350	Xenon-135	Air	kBq	4.1741841	1.9785462	1.657074

Appendix 9: continued

Title: Comparing 1 ton 'Emulsion, produced by Aquapel process', 1 ton 'Emulsion, produced by Hi-phase/composite process using liquid resin' and 1 ton 'Emulsion, produced by Hi-phase/composite process using solid rosin'
Method: IMPACT 2002+ V2.03 / IMPACT 2002+
Compartment: All compartments
Per sub-compartment: No
Default units: No
Indicator: Inventory
Relative mode: Non

351	Xenon-135m	Air	kBq	2.6028654	1.214291	1.0217813
352	Xenon-137	Air	Bq	76.995739	32.445443	28.17024
353	Xenon-138	Air	Bq	585.4822	254.71558	218.93941
354	Xylene	Air	g	17.561904	18.655262	17.877676
355	Zinc	Air	mg	311.46658	395.83373	163.87473
356	Zinc-65	Air	µBq	608.82459	248.77453	218.14755
357	Zirconium	Air	µg	6.5893019	2.8253125	2.5347698
358	Zirconium-95	Air	µBq	595.10292	243.16766	213.23095
359	Acenaphthene	Water	µg	10.420863	8.7469114	8.8629807
360	Acenaphthylene	Water	ng	651.72276	547.03353	554.29255
361	Acetic acid	Water	mg	0.82266796	1.6986774	13.248498
362	Acidity, unspecified	Water	mg	6.8051028	12.38441	19.172564
363	Actinides, radioactive, unspecified	Water	Bq	9.5816905	9.3477738	8.3338151
364	Aluminum	Water	kg	11.792149	12.469091	12.068594
365	Ammonium, ion	Water	kg	21.012454	20.998318	20.996433
366	Antimony	Water	g	2.2701102	2.3622264	2.3034136
367	Antimony-122	Water	mBq	9.1026187	3.7194616	3.2615536
368	Antimony-124	Water	Bq	2.1125545	1.8918146	1.7126517
369	Antimony-125	Water	Bq	2.583457	2.3924695	2.2108064
370	AOX, Adsorbable Organic Halogen as Cl	Water	g	0.005518453	52.300523	0.005952324
371	Arsenic, ion	Water	g	1.8869373	1.8945874	1.8665543
372	Barite	Water	mg	4.3701623	6.5717554	22.285328
373	Barium	Water	g	11.788919	12.238985	11.43655
374	Barium-140	Water	mBq	39.874303	16.293217	14.287336
375	Benzene	Water	mg	124.77251	118.07432	251.13908
376	Benzene, ethyl-	Water	mg	40.213395	33.754401	34.202129
377	Beryllium	Water	mg	740.42495	801.37044	768.87538
378	BOD5, Biological Oxygen Demand	Water	kg	19.606504	19.948912	19.503514
379	Boron	Water	g	16.285847	17.755762	16.751746
380	Bromate	Water	g	2.6519777	3.9484825	2.6502153
381	Bromine	Water	g	5.6948566	5.7611371	5.6140965
382	Butene	Water	mg	0.73057828	1.2882134	0.71859789
383	Cadmium, ion	Water	mg	314.64343	365.03025	306.87103
384	Calcium, ion	Water	kg	94.618151	94.898601	94.356949
385	Carbonate	Water	mg	161.38321	194.34821	226.89134
386	Carboxylic acids, unspecified	Water	g	7.0697747	5.8825701	5.961491
387	Cerium-141	Water	mBq	15.942398	6.5142943	5.7123106
388	Cerium-144	Water	mBq	4.8533874	1.9831642	1.7390142
389	Cesium	Water	mg	1.6753799	1.4062559	1.4249165
390	Cesium-134	Water	Bq	2.3368382	2.3511547	2.1832302
391	Cesium-136	Water	mBq	2.8294644	1.1561601	1.0138236
392	Cesium-137	Water	Bq	1107.4981	1078.0432	961.26706
393	Chlorate	Water	g	20.256572	40.481158	20.247952
394	Chloride	Water	kg	97.820259	98.914223	98.334335
395	Chlorinated solvents, unspecified	Water	mg	5.8110347	8.6582019	5.8422122
396	Chlorine	Water	g	212.15963	212.0549	212.05063
397	Chloroform	Water	pg	0.026892701	0.046698338	0.10789502
398	Chromium-51	Water	Bq	4.4879338	2.8221339	2.5763449
399	Chromium VI	Water	g	17.94793	18.788302	18.044096
400	Chromium, ion	Water	mg	124.25422	119.60748	86.764592
401	Cobalt	Water	g	4.5709425	4.7165578	4.6140806
402	Cobalt-57	Water	mBq	89.817875	36.700882	32.182586
403	Cobalt-58	Water	Bq	23.482236	16.605421	15.037563
404	Cobalt-60	Water	Bq	20.215738	14.018108	12.735686
405	COD, Chemical Oxygen Demand	Water	kg	59.584692	67.575109	59.418885
406	Copper, ion	Water	g	60.04133	63.637072	59.372118
407	Cumene	Water	mg	12.267174	23.09028	154.37318
408	Cyanide	Water	mg	30.506915	15.136865	13.688548
409	Dichromate	Water	mg	1.0226597	1.0216981	1.0225455
410	DOC, Dissolved Organic Carbon	Water	kg	15.118432	15.530571	15.067825
411	Ethane, 1,2-dichloro-	Water	mg	4.1281562	1.4846883	1.4704222
412	Ethene	Water	mg	4.2443181	8.680248	63.783117
413	Ethene, chloro-	Water	µg	1.8225847	3.2199161	16.897882
414	Ethylene diamine	Water	µg	2.495496	2.8504872	2.7128367
415	Ethylene oxide	Water	mg	0.000741522	5.2603736	0.000679732
416	Fluoride	Water	g	81.887235	80.806024	80.045448
417	Fluosilicic acid	Water	mg	4.6077922	5.2663061	5.0094853
418	Formaldehyde	Water	mg	0.76772077	75.876995	8.1412099
419	Glutaraldehyde	Water	µg	0.53952597	0.81132779	2.7512748
420	Heat, waste	Water	GJ	2.4203565	2.4575394	2.4117989

Appendix 9: continued

Title: Comparing 1 ton 'Emulsion, produced by Aquapel process', 1 ton 'Emulsion, produced by Hi-phase/composite process using liquid resin' and 1 ton 'Emulsion, produced by Hi-phase/composite process using solid rosin'
Method: IMPACT 2002+ V2.03 / IMPACT 2002+
Compartment: All compartments
Per sub-compartment: No
Default units: No
Indicator: Inventory
Relative mode: Non

421	Hydrocarbons, aliphatic, alkanes, unspecified	Water	mg	217.79938	182.81326	185.23915
422	Hydrocarbons, aliphatic, unsaturated	Water	mg	20.104558	16.87507	17.098999
423	Hydrocarbons, aromatic	Water	mg	886.9117	747.64094	756.06209
424	Hydrocarbons, unspecified	Water	mg	28.935285	38.514291	72.506969
425	Hydrogen-3, Tritium	Water	kBq	2557.1159	2494.1495	2225.9206
426	Hydrogen peroxide	Water	g	1.120283	2.0212873	1.1198195
427	Hydrogen sulfide	Water	g	0.35073495	1.5268963	0.34780956
428	Hydroxide	Water	µg	0.62084208	0.98882712	2.893807
429	Hypochlorite	Water	mg	32.362398	42.417683	28.907786
430	Iodide	Water	mg	169.16844	142.64304	143.86045
431	Iodine-131	Water	mBq	429.73366	366.78672	333.03119
432	Iodine-133	Water	mBq	25.032201	10.228519	8.9692723
433	Iron-59	Water	mBq	6.8818873	2.8120386	2.4658447
434	Iron, ion	Water	kg	15.572373	15.579869	15.552413
435	Lanthanum-140	Water	mBq	42.469428	17.353622	15.217194
436	Lead	Water	g	4.0887012	5.6605309	3.9322065
437	Lead-210	Water	Bq	847.86876	262.64986	260.84903
438	Magnesium	Water	kg	11.425235	11.544267	11.447453
439	Manganese	Water	g	88.346472	116.8516	88.216412
440	Manganese-54	Water	Bq	1.5546977	1.1458325	1.0458415
441	Mercury	Water	mg	137.56398	141.99464	136.20492
442	Methane, dichloro-, HCC-30	Water	µg	7.541839	11.659809	42.558935
443	Methanol	Water	mg	23.770476	31.773608	9.6902011
444	Molybdenum	Water	g	1.7919192	1.8011339	1.7820111
445	Molybdenum-99	Water	mBq	14.642547	5.9831564	5.2465618
446	Nickel, ion	Water	g	20.28039	21.3018	20.46706
447	Niobium-95	Water	mBq	376.58736	360.59833	340.82493
448	Nitrate	Water	kg	98.738983	94.273888	94.262127
449	Nitrite	Water	kg	1.2300108	1.2291429	1.2291371
450	Nitrogen	Water	kg	0.93714838	1.007248	0.9359978
451	Nitrogen, organic bound	Water	g	0.22211645	3.4232153	0.23406838
452	Oils, unspecified	Water	g	102.1077	81.650504	82.934158
453	PAH, polycyclic aromatic hydrocarbons	Water	mg	9.6841402	8.1553908	8.1945812
454	Paraffins	Water	ng	0.52170658	0.96665786	4.6826064
455	Phenol	Water	mg	181.06665	141.37421	137.02299
456	Phosphate	Water	kg	5.621658	5.5985563	5.5948285
457	Phosphorus	Water	g	12.348334	9.3292172	3.7961131
458	Polonium-210	Water	Bq	1292.5949	399.34013	397.03496
459	Potassium-40	Water	Bq	105.32751	34.947138	33.77408
460	Potassium, ion	Water	kg	1.6693356	1.8248247	1.7013242
461	Propene	Water	mg	5.6342242	10.390514	57.952943
462	Propylene oxide	Water	µg	143.92918	162.8253	141.71318
463	Protactinium-234	Water	Bq	15.568265	14.694777	13.106924
464	Radioactive species, alpha emitters	Water	mBq	751.41341	232.36651	230.989
465	Radioactive species, Nuclides, unspecified	Water	kBq	5.7359584	5.5955723	4.9878339
466	Radium-224	Water	Bq	83.768993	70.312793	71.245827
467	Radium-226	Water	kBq	10.771001	9.546989	8.559237
468	Radium-228	Water	Bq	167.53799	140.62559	142.49165
469	Rubidium	Water	mg	17.355512	14.630512	14.755748
470	Ruthenium-103	Water	mBq	3.0897093	1.2624999	1.1070718
471	Scandium	Water	g	4.9853325	5.4118417	5.1906586
472	Selenium	Water	g	1.3179231	1.4182919	1.3639172
473	Silicon	Water	kg	28.38829	30.782533	29.455812
474	Silver-110	Water	Bq	17.875624	11.743917	10.572174
475	Silver, ion	Water	mg	2.7825416	4.6166865	2.2864556
476	Sodium-24	Water	mBq	110.78941	45.270156	39.696885
477	Sodium formate	Water	µg	62.248563	73.332719	66.939051
478	Sodium, ion	Water	kg	5.9160855	6.1381227	5.8679371
479	Solids, inorganic	Water	g	117.52746	338.75467	113.64638
480	Solved solids	Water	g	26.713343	36.813724	27.520025
481	Strontium	Water	g	97.277761	103.07859	99.329014
482	Strontium-89	Water	mBq	499.80735	365.51834	339.63782
483	Strontium-90	Water	kBq	2.3978793	2.5945105	1.8358091
484	Sulfate	Water	kg	285.53282	285.53613	285.09659
485	Sulfide	Water	mg	15.829511	6.7326264	5.5852513
486	Sulfite	Water	mg	85.84366	111.20103	75.952564
487	Sulfur	Water	mg	313.27913	216.67541	211.32091
488	Suspended solids, unspecified	Water	g	18.185387	316.1261	15.905646
489	t-Butyl methyl ether	Water	mg	3.7521882	4.1104857	3.822568
490	Technetium-99m	Water	mBq	336.67595	137.74837	120.73926

Appendix 9: continued

Title: Comparing 1 ton 'Emulsion, produced by Aquapel process', 1 ton 'Emulsion, produced by Hi-phase/composite process using liquid resin' and 1 ton 'Emulsion, produced by Hi-phase/composite process using solid rosin'
Method: IMPACT 2002+ V2.03 / IMPACT 2002+
Compartment: All compartments
Per sub-compartment: No
Default units: No
Indicator: Inventory
Relative mode: Non

491	Tellurium-123m	Water	mBq	261.92317	258.47128	237.9651
492	Tellurium-132	Water	µBq	847.83241	346.43658	303.7863
493	Thallium	Water	mg	423.28041	456.40107	439.17749
494	Thorium-228	Water	Bq	345.44069	284.43685	288.15724
495	Thorium-230	Water	kBq	2.1241379	2.004959	1.7883118
496	Thorium-232	Water	mBq	586.83091	660.23828	463.13649
497	Thorium-234	Water	Bq	15.570512	14.696919	13.108871
498	Tin, ion	Water	g	5.5025482	5.7991306	5.5135536
499	Titanium, ion	Water	g	360.4741	390.23786	373.68886
500	TOC, Total Organic Carbon	Water	kg	14.663951	18.735452	14.611545
501	Toluene	Water	mg	211.01564	180.67425	180.2411
502	Tributyltin compounds	Water	mg	2.367466	2.2762084	37.850328
503	Triethylene glycol	Water	mg	19.514761	7.4608836	5.9927907
504	Tungsten	Water	g	1.051719	1.1425284	1.0936721
505	Uranium-234	Water	Bq	18.681919	17.633733	15.728309
506	Uranium-235	Water	Bq	30.825165	29.095659	25.951709
507	Uranium-238	Water	Bq	481.96529	179.06682	173.36752
508	Uranium alpha	Water	Bq	896.84471	846.52106	755.04375
509	Vanadium, ion	Water	g	33.27945	35.940171	34.508385
510	VOC, volatile organic compounds, unspecified origin	Water	mg	625.20898	529.11356	531.67252
511	Xylene	Water	mg	170.46339	142.78836	144.59626
512	Zinc-65	Water	Bq	1.5020538	0.61376091	0.53819996
513	Zinc, ion	Water	g	68.038712	73.480403	67.811511
514	Zirconium-95	Water	mBq	17.394204	7.107523	6.2325061
515	Aclonifen	Soil	mg	0.030724251	1.1624492	0.030720231
516	Aluminum	Soil	g	794.60358	793.99485	794.05829
517	Antimony	Soil	ng	2.3253725	2.2448445	2.1509234
518	Arsenic	Soil	mg	104.78624	104.7681	104.77586
519	Atrazine	Soil	g	10.977674	3.357093	3.3570926
520	Barium	Soil	µg	166.29978	248.76556	857.57033
521	Bentazone	Soil	µg	15.647364	592.01656	15.645317
522	Boron	Soil	µg	9.8640347	12.938666	30.631107
523	Cadmium	Soil	mg	121.50568	89.476793	89.214498
524	Calcium	Soil	kg	2.6915248	2.691068	2.6912337
525	Carbetamide	Soil	mg	54.502049	16.878791	16.675172
526	Carbon	Soil	kg	9.3672048	9.3410045	9.3417956
527	Chloride	Soil	mg	13.951676	16.440146	28.937672
528	Chlorothalonil	Soil	mg	5.1503141	5.8845415	5.5984711
529	Chromium	Soil	g	3.9221769	3.4563976	3.4537089
530	Chromium VI	Soil	µg	10.736819	17.283603	50.619479
531	Cobalt	Soil	mg	429.42643	429.3509	429.38293
532	Copper	Soil	g	15.669209	15.181999	15.180908
533	Cypermethrin	Soil	mg	2.774488	0.85316192	0.84875608
534	Dinoseb	Soil	mg	1.399835	1.5993951	1.5216423
535	Fenpiclonil	Soil	µg	203.69704	271.61	221.32951
536	Fluoride	Soil	µg	22.112602	34.689802	118.28958
537	Glyphosate	Soil	g	4.1623214	1.2728857	1.2728912
538	Heat, waste	Soil	MJ	20.892593	10.910661	7.3935229
539	Iron	Soil	kg	7.1748146	7.1677655	7.1645748
540	Lead	Soil	g	4.2485998	4.175719	4.1749146
541	Linuron	Soil	mg	0.23776756	8.9959136	0.23773645
542	Magnesium	Soil	g	301.60427	301.55322	301.57211
543	Mancozeb	Soil	mg	6.7051781	7.6610666	7.2886324
544	Manganese	Soil	g	14.136185	14.135537	14.132102
545	Mercury	Soil	mg	87.09855	78.429327	78.427779
546	Metaldehyde	Soil	mg	24.043619	7.3934725	7.3552916
547	Metolachlor	Soil	g	9.8056112	3.0631848	2.9998561
548	Metribuzin	Soil	µg	235.66862	269.26547	256.17543
549	Molybdenum	Soil	mg	253.82056	253.7753	253.79582
550	Napropamide	Soil	mg	42.54992	13.084206	13.016637
551	Nickel	Soil	g	1.5805495	1.4576209	1.4562393
552	Oils, biogenic	Soil	g	0.19747899	7.6635248	0.19748466
553	Oils, unspecified	Soil	g	105.54394	82.572081	83.809733
554	Orbencarb	Soil	mg	1.2717735	1.4530772	1.3824375
555	Phosphorus	Soil	mg	25.741683	26.670674	24.442249
556	Pirimicarb	Soil	µg	1.4832397	56.118236	1.4830456
557	Potassium	Soil	mg	143.17663	148.35468	136.04972
558	Silicon	Soil	kg	1.5860572	1.5857797	1.5858944
559	Silver	Soil	ng	28.728998	53.174947	263.83706
560	Sodium	Soil	mg	0.60031578	0.92845804	3.3820931
561	Strontium	Soil	µg	68.400537	73.780899	80.498116
562	Sulfur	Soil	g	830.15739	830.00906	830.0777
563	Tebutam	Soil	mg	100.83748	31.007776	30.847647
564	Teflubenzuron	Soil	µg	15.693803	17.931108	17.059407
565	Tin	Soil	g	1.0667685	1.0665764	1.0666666
566	Titanium	Soil	mg	3.6227591	3.7524294	3.4300368
567	Vanadium	Soil	µg	103.69492	107.40649	98.178587
568	Zinc	Soil	g	44.006956	42.177651	42.012703

Appendix 10: Aquapel Process - Relative contribution of life cycle stages to four damage categories

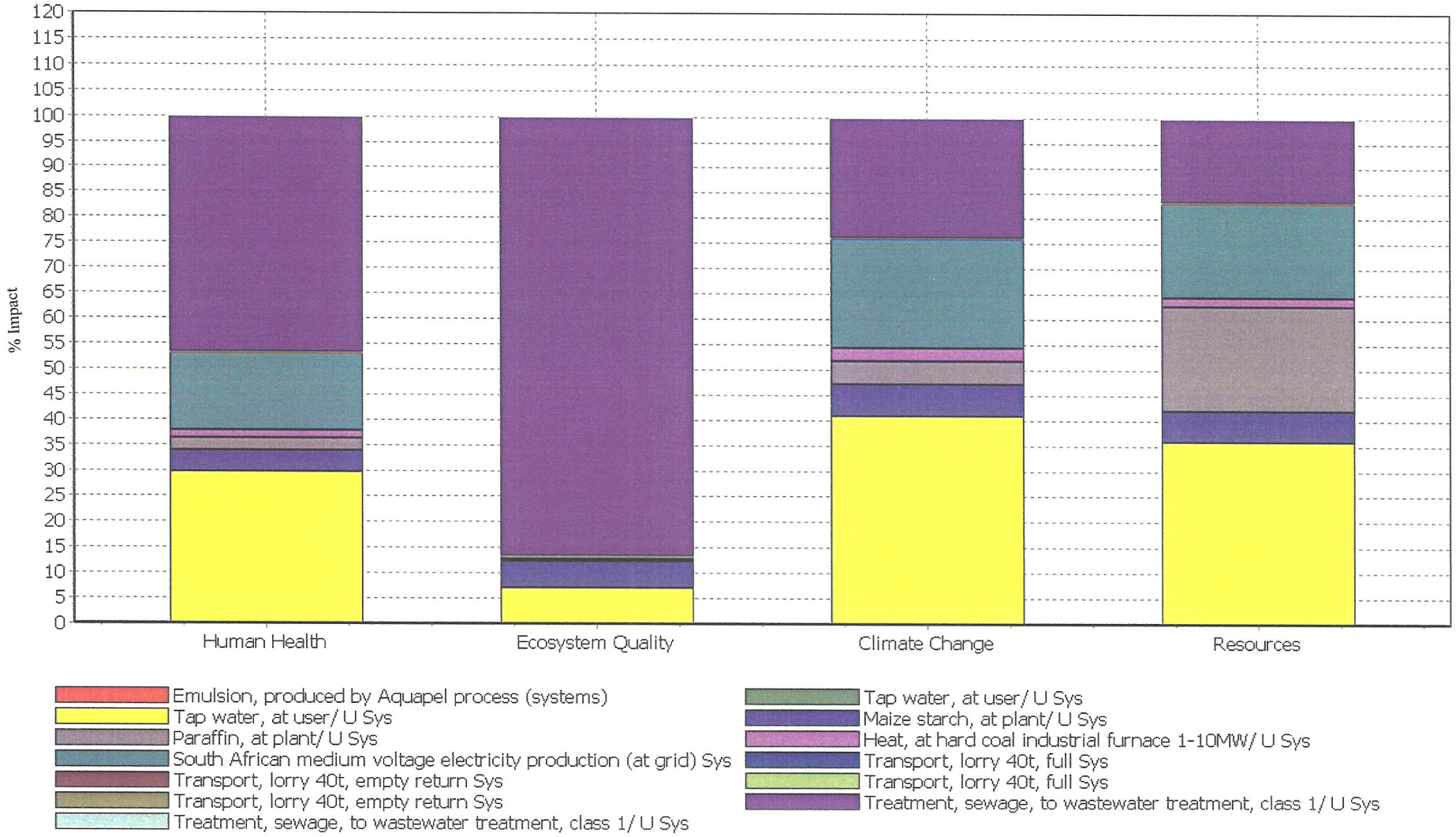


Figure 10 Aquapel Process -Relative contribution of life cycle stages to four damage categories

Appendix 11: Hi-phase/composite Process (liquid rosin) - Relative contribution of life cycle stages to four damage categories

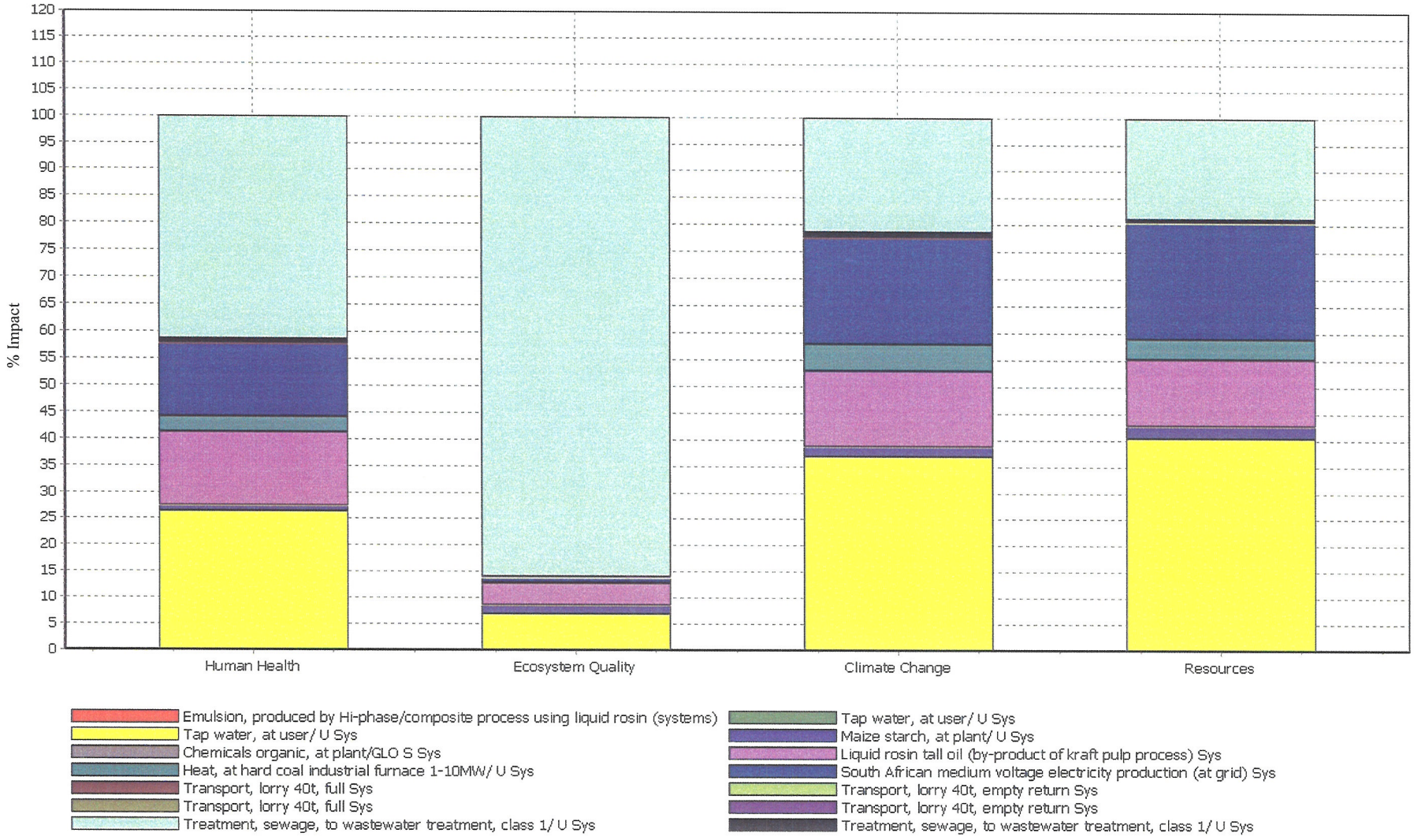


Figure 11 Hi-phase/composite Process using liquid rosin - Relative contribution of life cycle stages to four damage categories

Appendix 12: Hi-phase/composite Process (solid rosin) - Relative contribution of life cycle stages to four damage categories

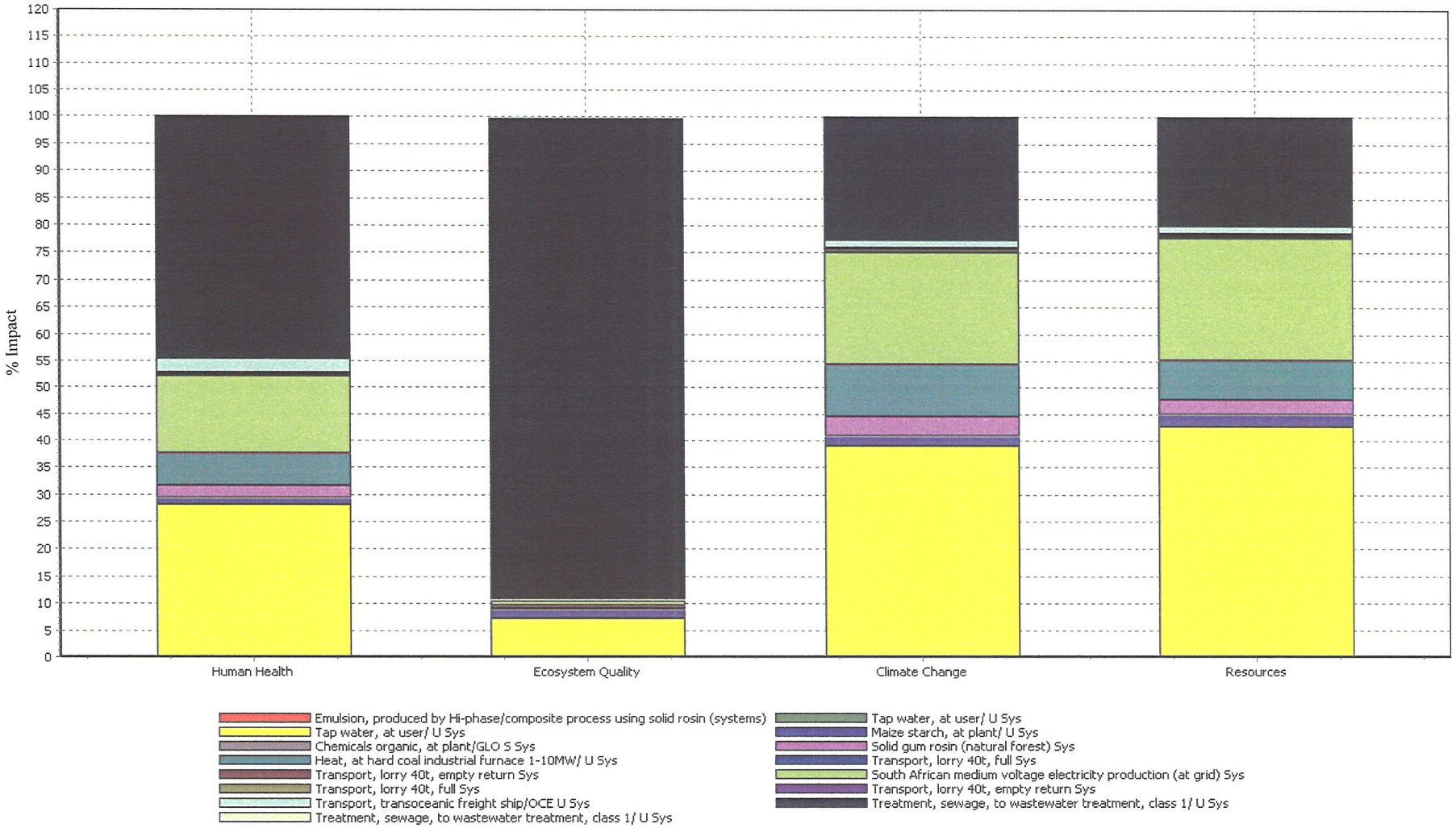
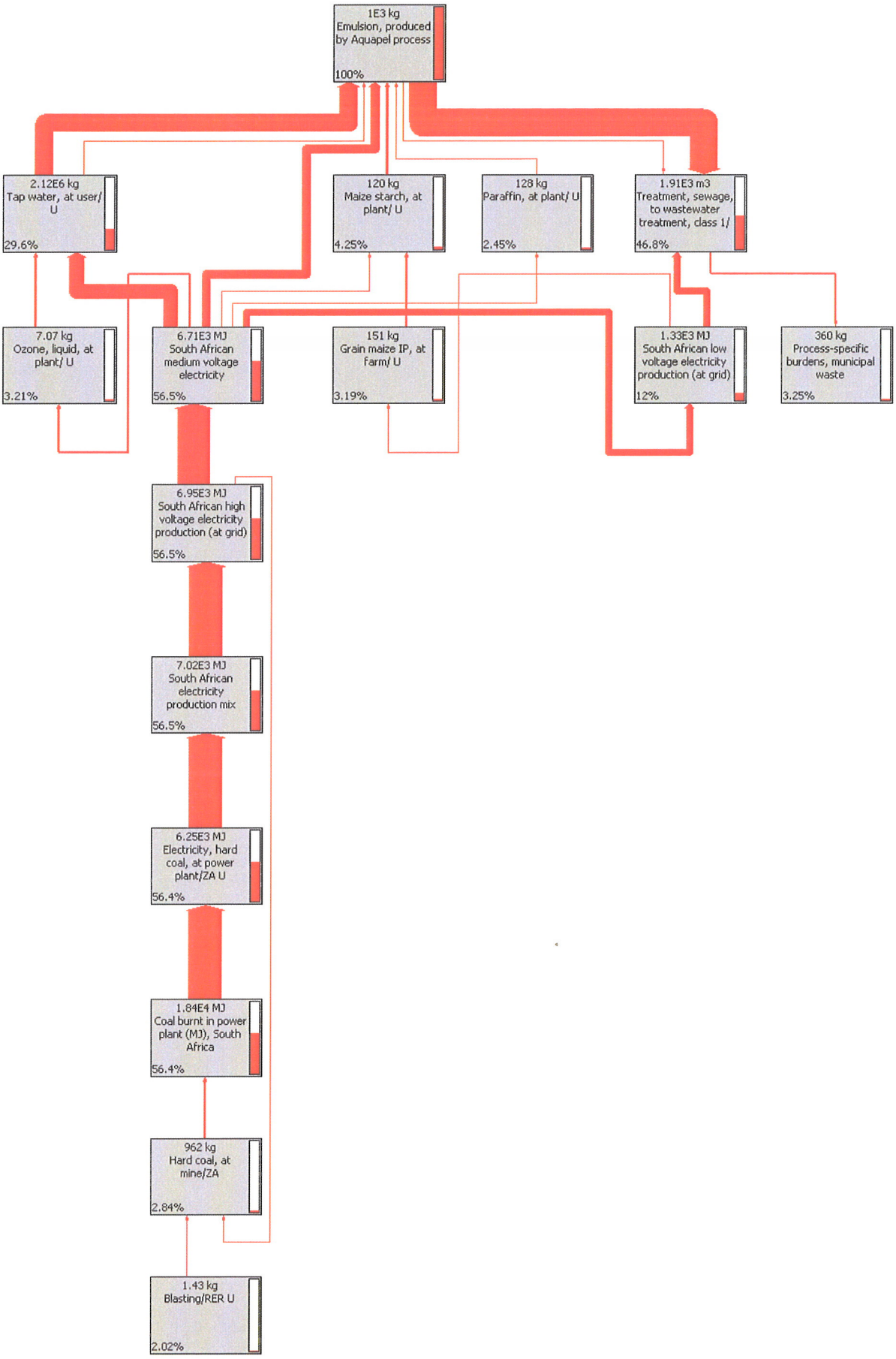


Figure 12 Hi-phase/composite Process using solid rosin - Relative contribution of life cycle stages to four damage categories

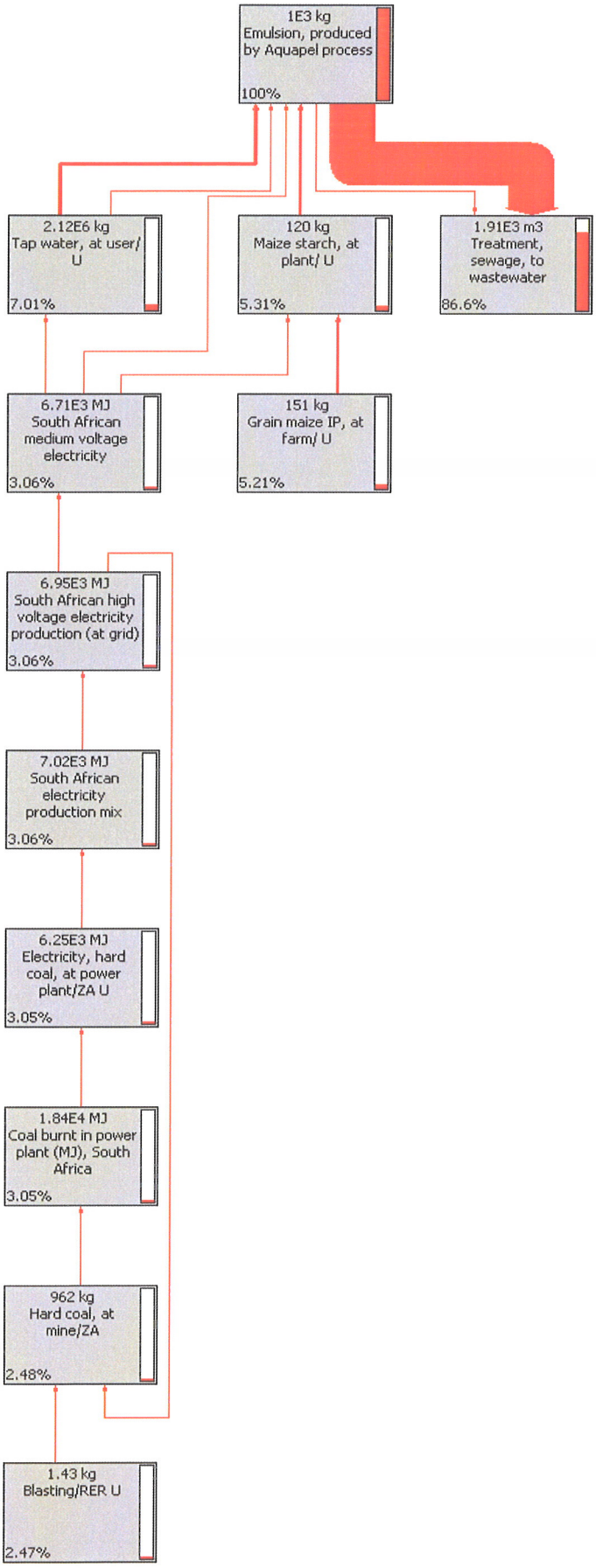
Appendix 13: Network Diagrams

Network diagrams for each process for the four damage categories. The thickness of the lines shows the relative contribution from that stage in the life cycle (also shown by the little thermometer in each block).

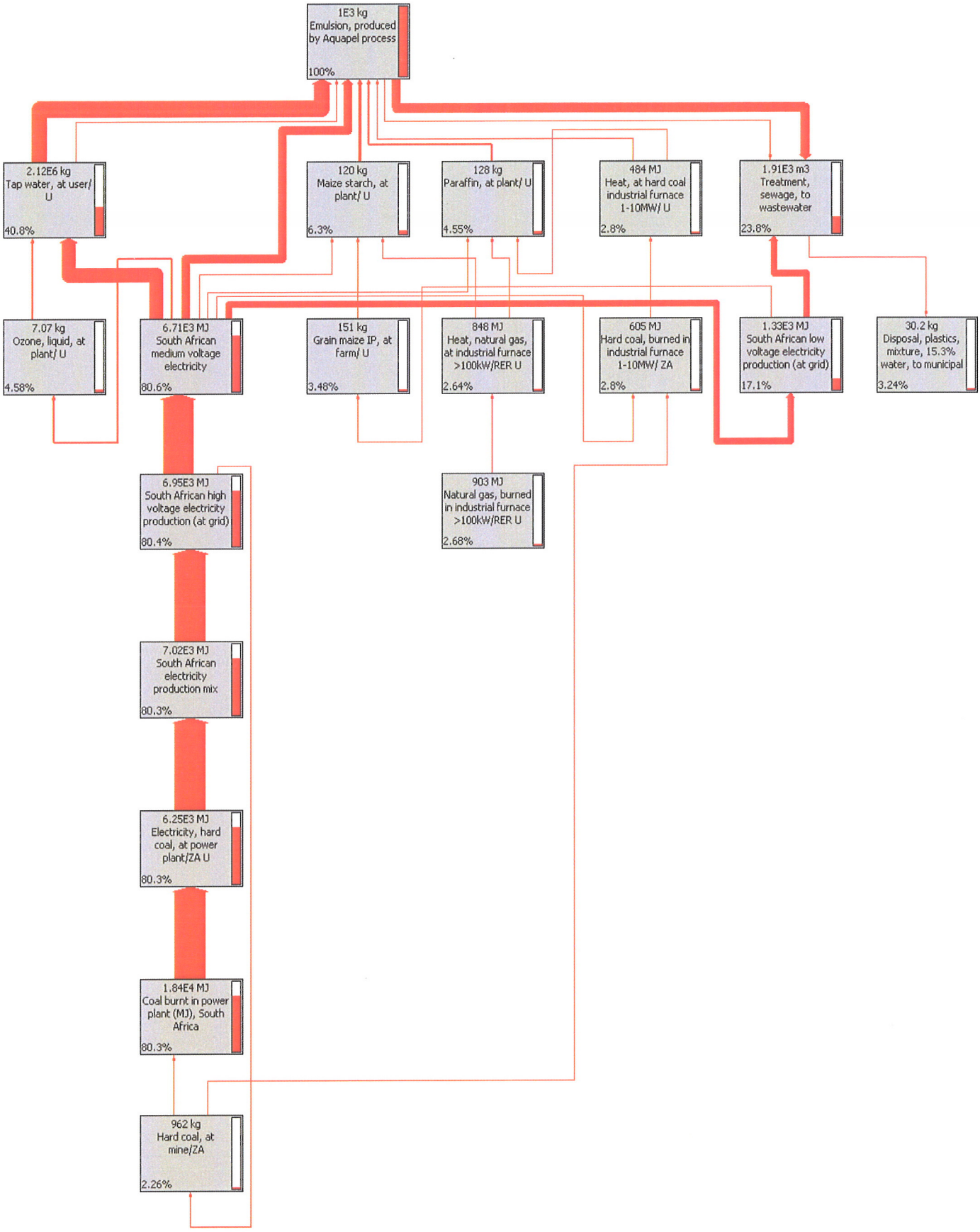
A 2% cut-off is applied in these diagrams (i.e. processes contributing less than 2% to the damage category are not shown) (other than for the Hi-phase composite process using solid resin, where a 5% cut-off is applied in the last two charts).


1E3 kg
Emulsion, produced by Aquapel process
100%
2.12E6 kg
Tap water, at user/ U
29.6%
120 kg
Maize starch, at plant/ U
4.25%
128 kg
Paraffin, at plant/ U
2.45%
1.91E3 m3
Treatment, sewage, to wastewater treatment, class 1/
46.8%
7.07 kg
Ozone, liquid, at plant/ U
3.21%
6.71E3 MJ
South African medium voltage electricity
56.5%
151 kg
Grain maize IP, at farm/ U
3.19%
1.33E3 MJ
South African low voltage electricity production (at grid)
12%
360 kg
Process-specific burdens, municipal waste
3.25%
6.95E3 MJ
South African high voltage electricity production (at grid)
56.5%
7.02E3 MJ
South African electricity production mix
56.5%
6.25E3 MJ
Electricity, hard coal, at power plant/ZA U
56.4%
1.84E4 MJ
Coal burnt in power plant (MJ), South Africa
56.4%
962 kg
Hard coal, at mine/ZA
2.84%
1.43 kg
Blasting/RER U
2.02%

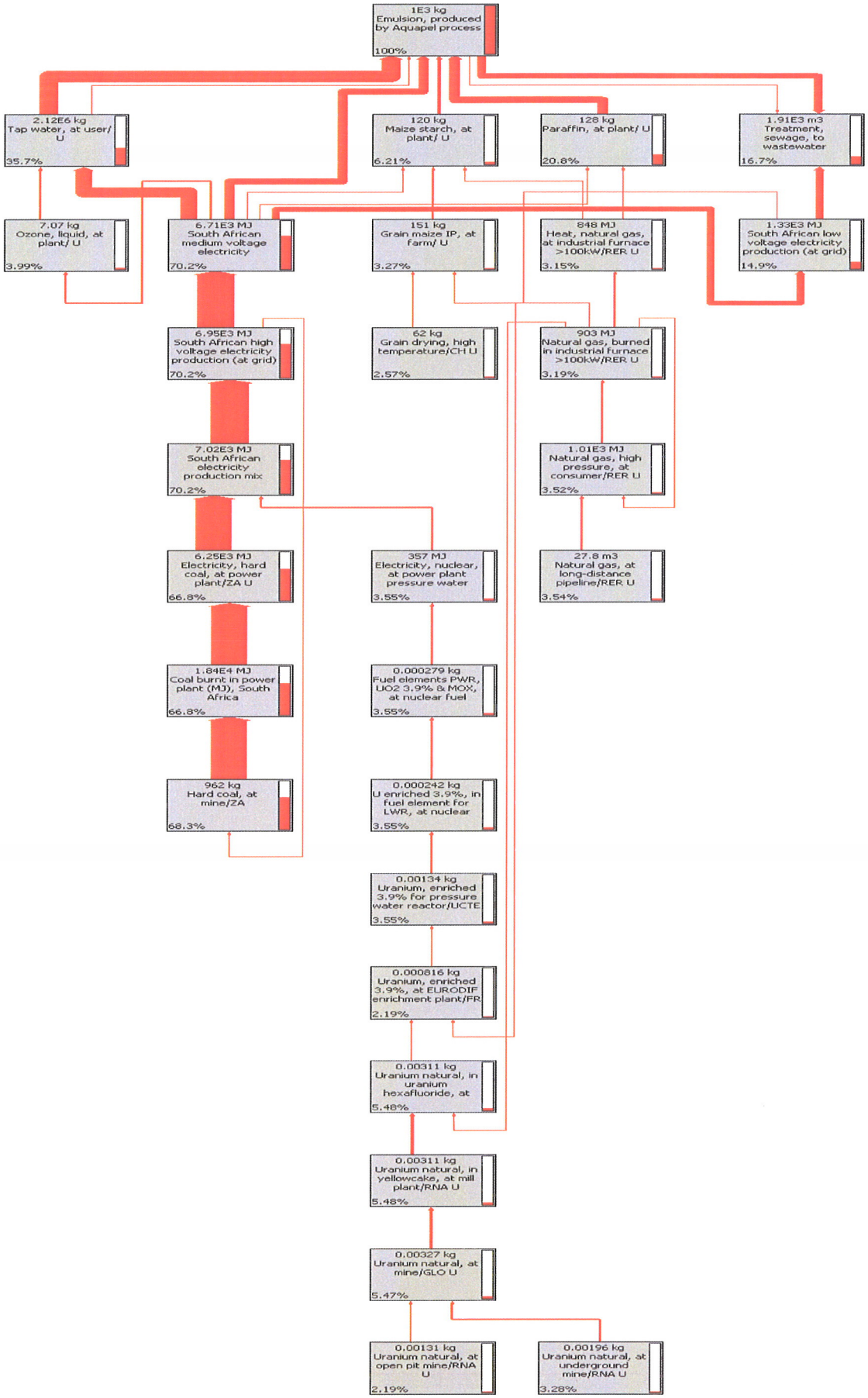
Appendix 13.2 Aquapel Process: Ecosystem Quality



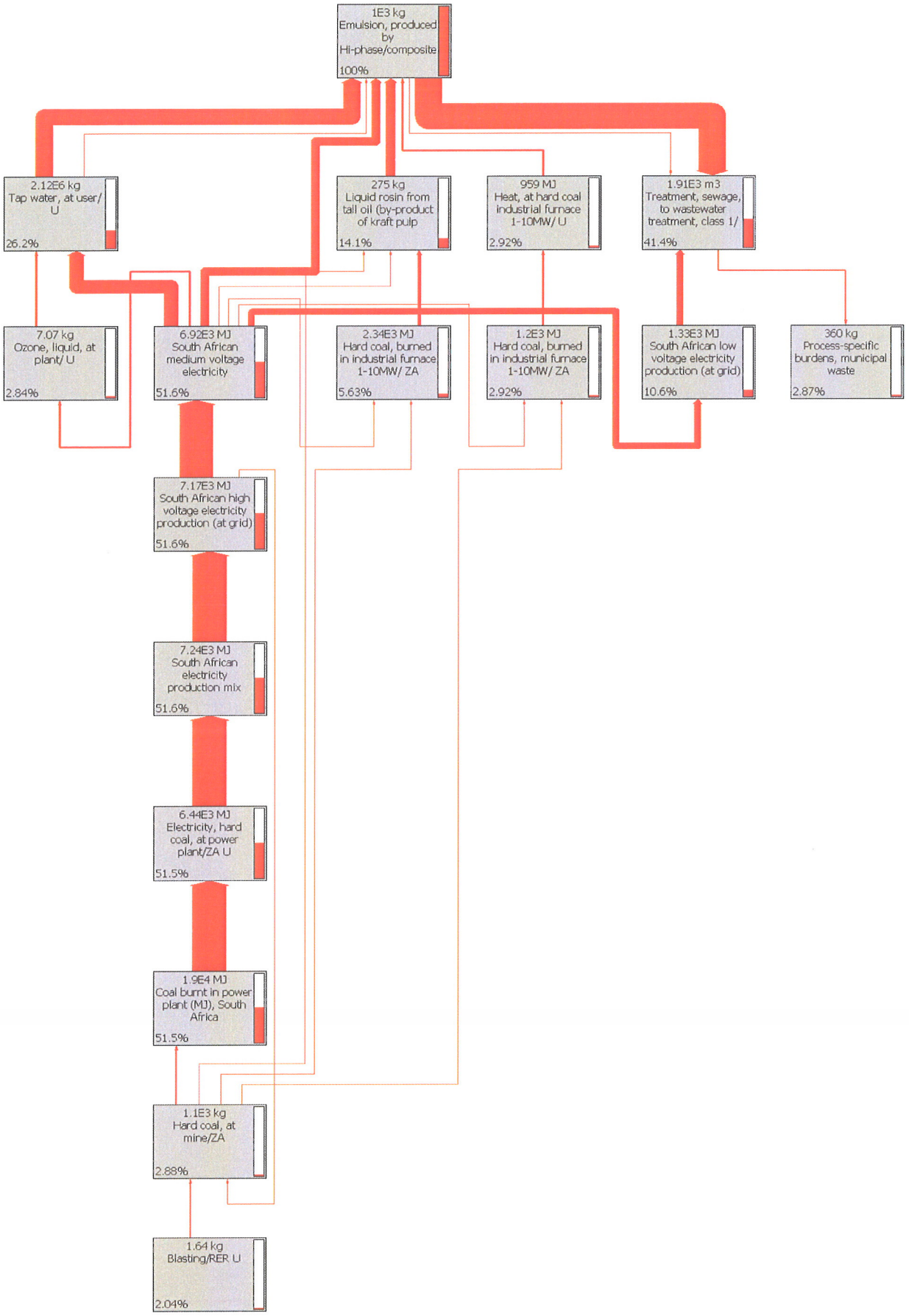
Appendix 13.3 Aquapel Process: Climate Change



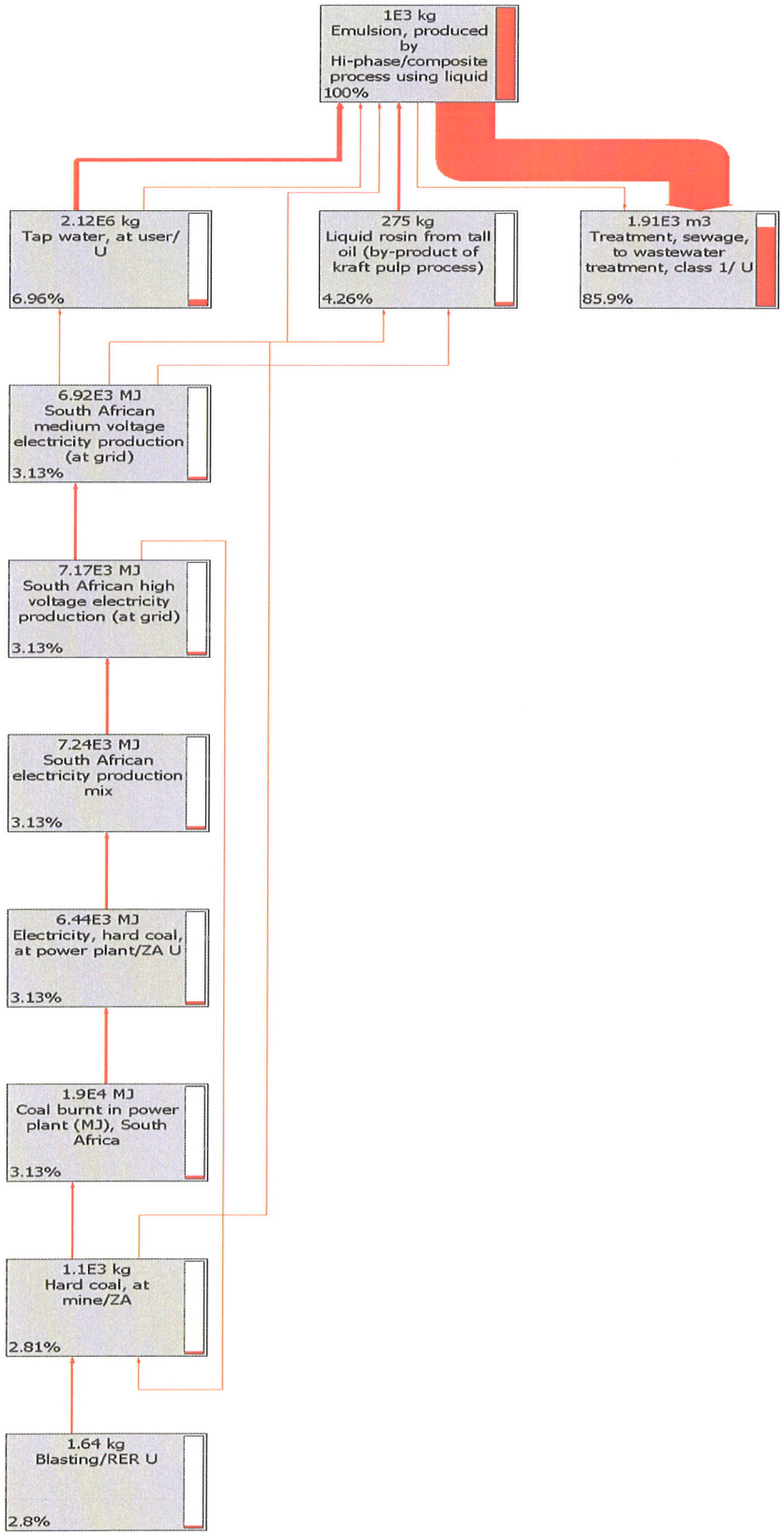
Appendix 13.4 Aquapel Process: Resources



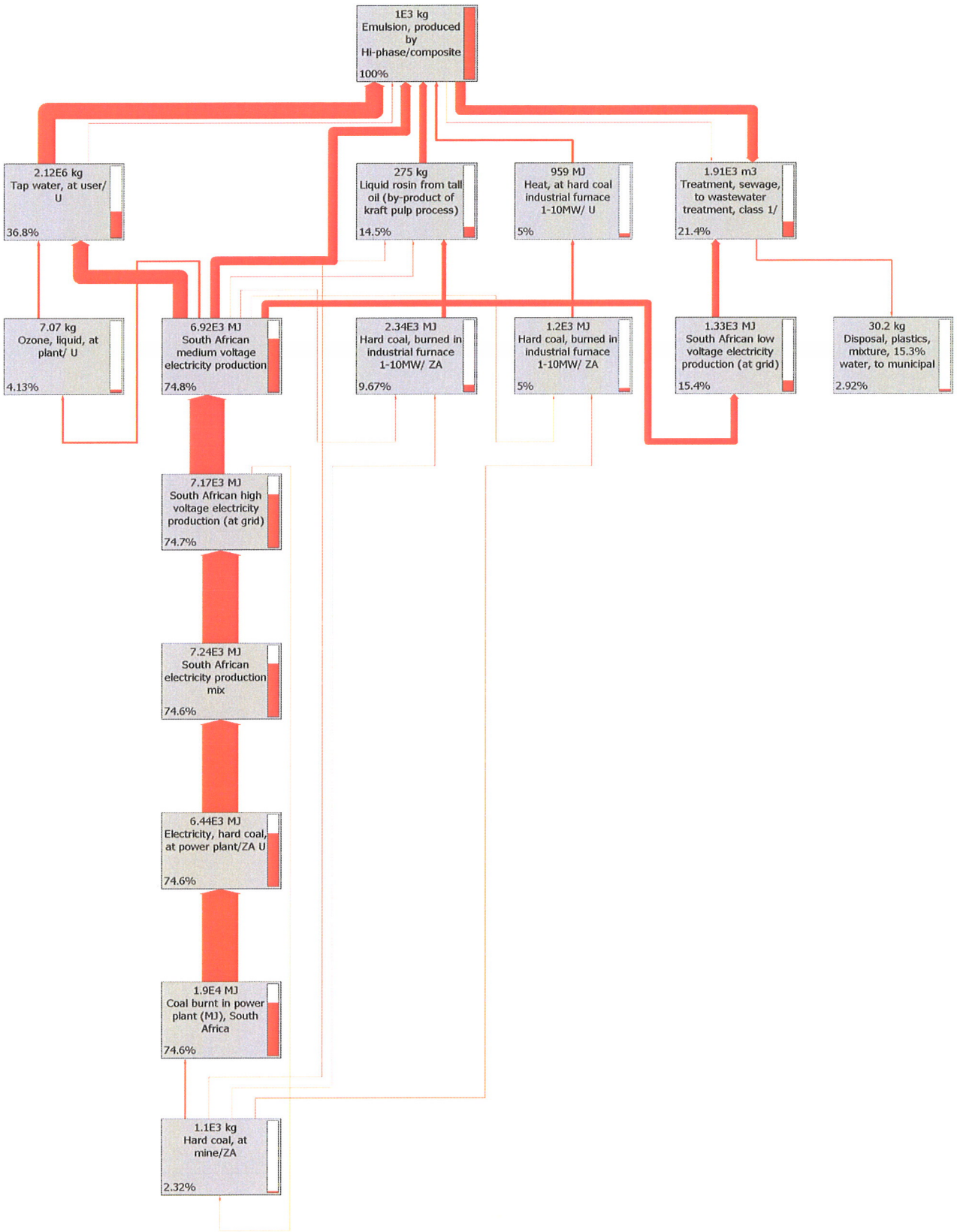
Appendix 13.5 Hi-phase/composite process using liquid rosin: Human Health



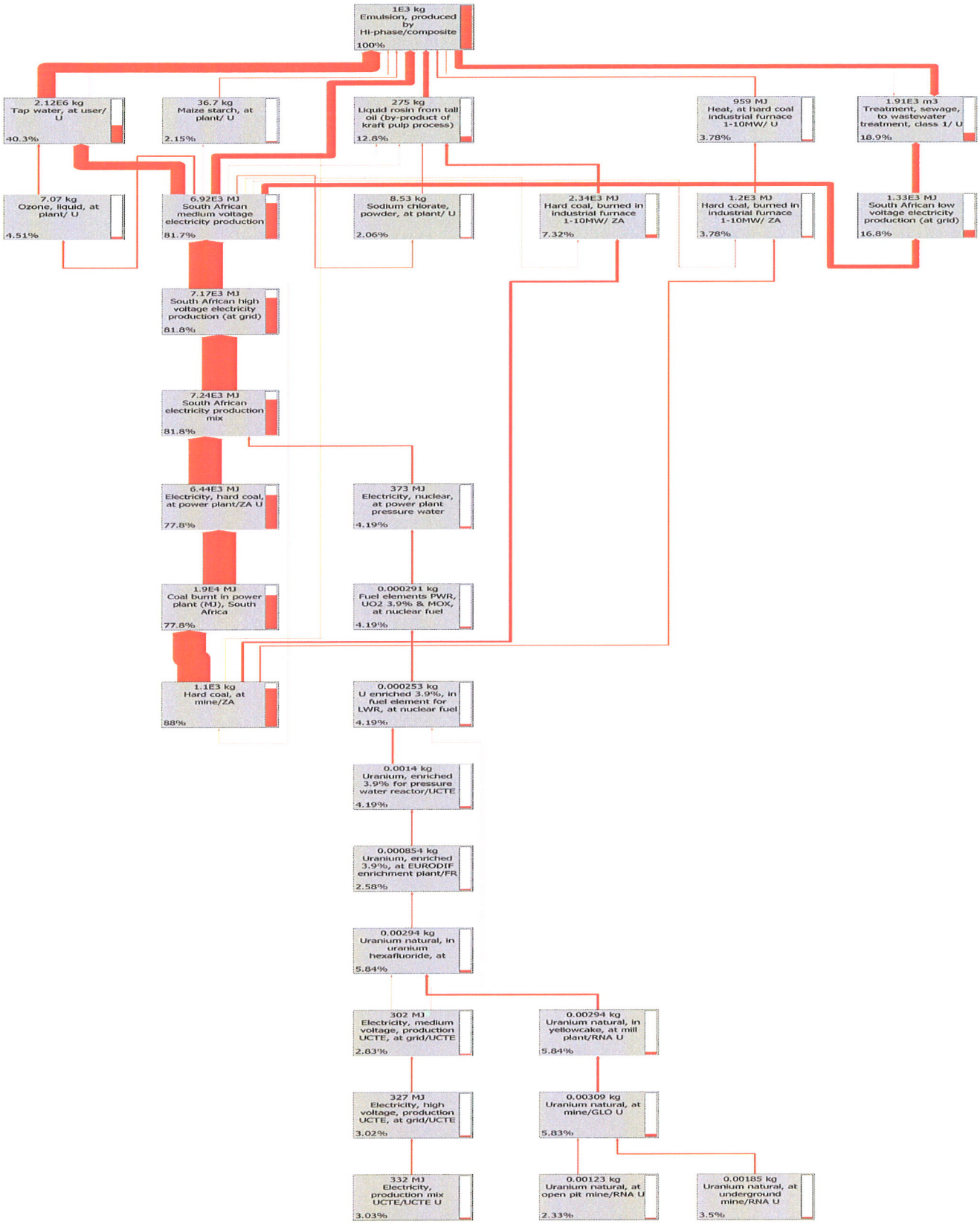
Appendix 13.6 Hi-phase/composite process using liquid rosin: Ecosystem Quality



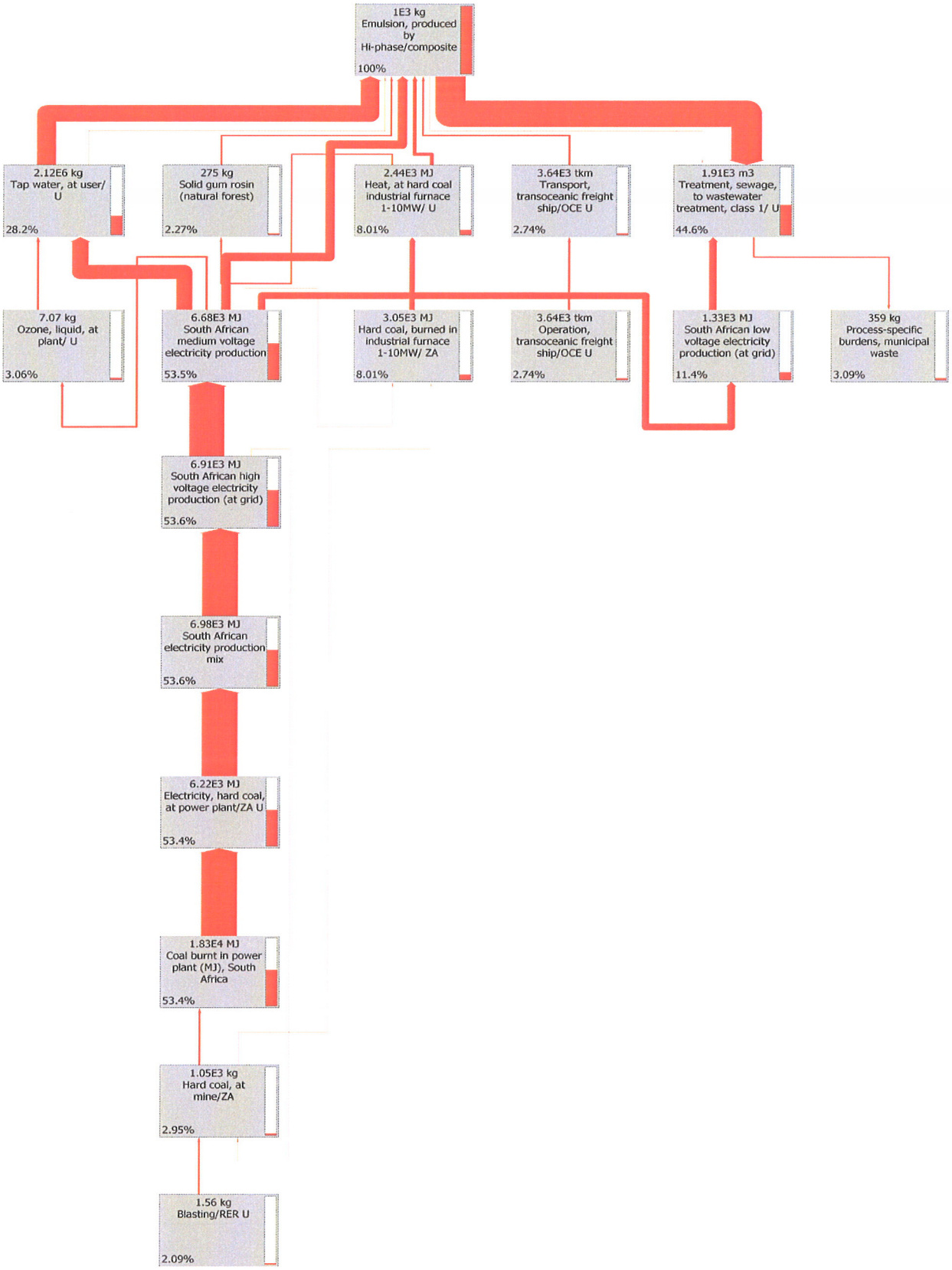
Appendix 13.7 Hi-phase/composite process using liquid rosin: Climate Change



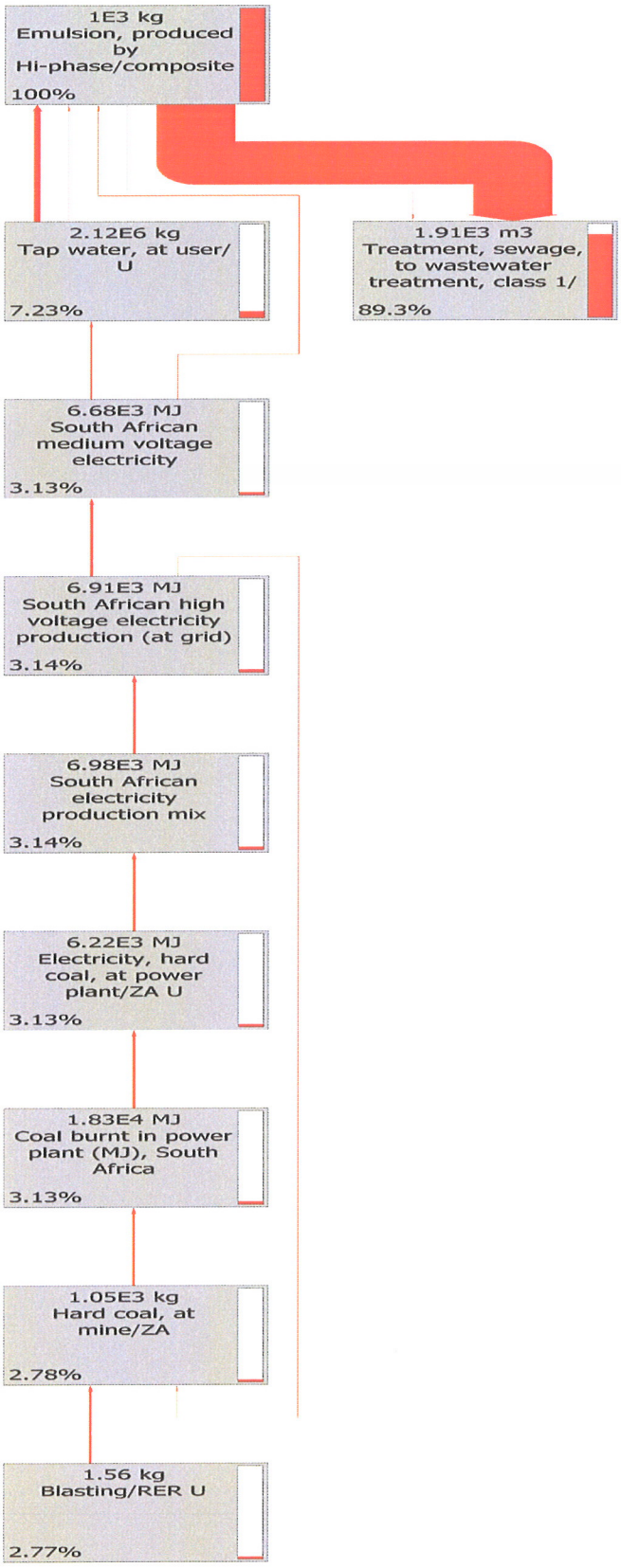
Appendix 13.8 Hi-phase/composite process using liquid rosin: Resources



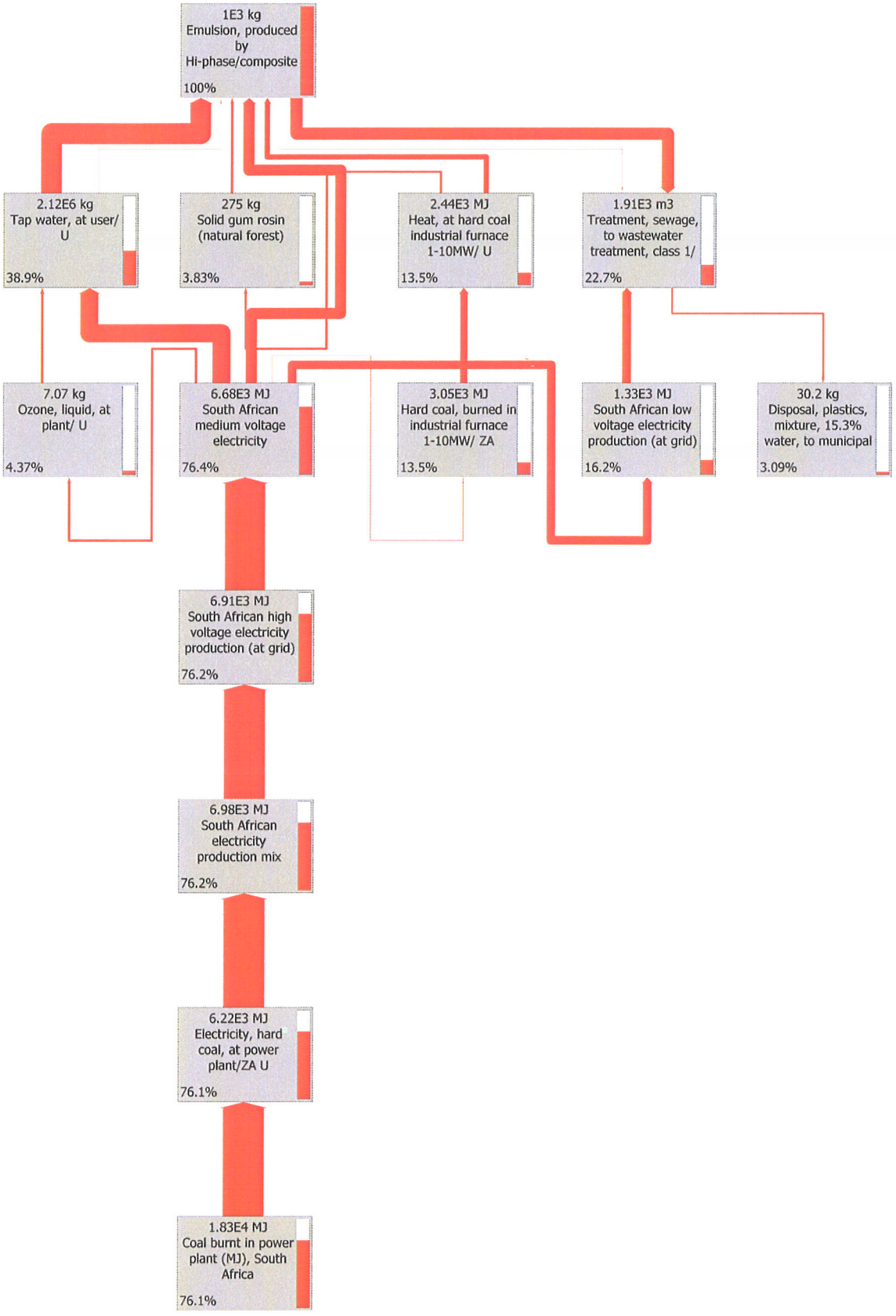
Appendix 13.9 Hi-phase/composite process using solid rosin: Human Health



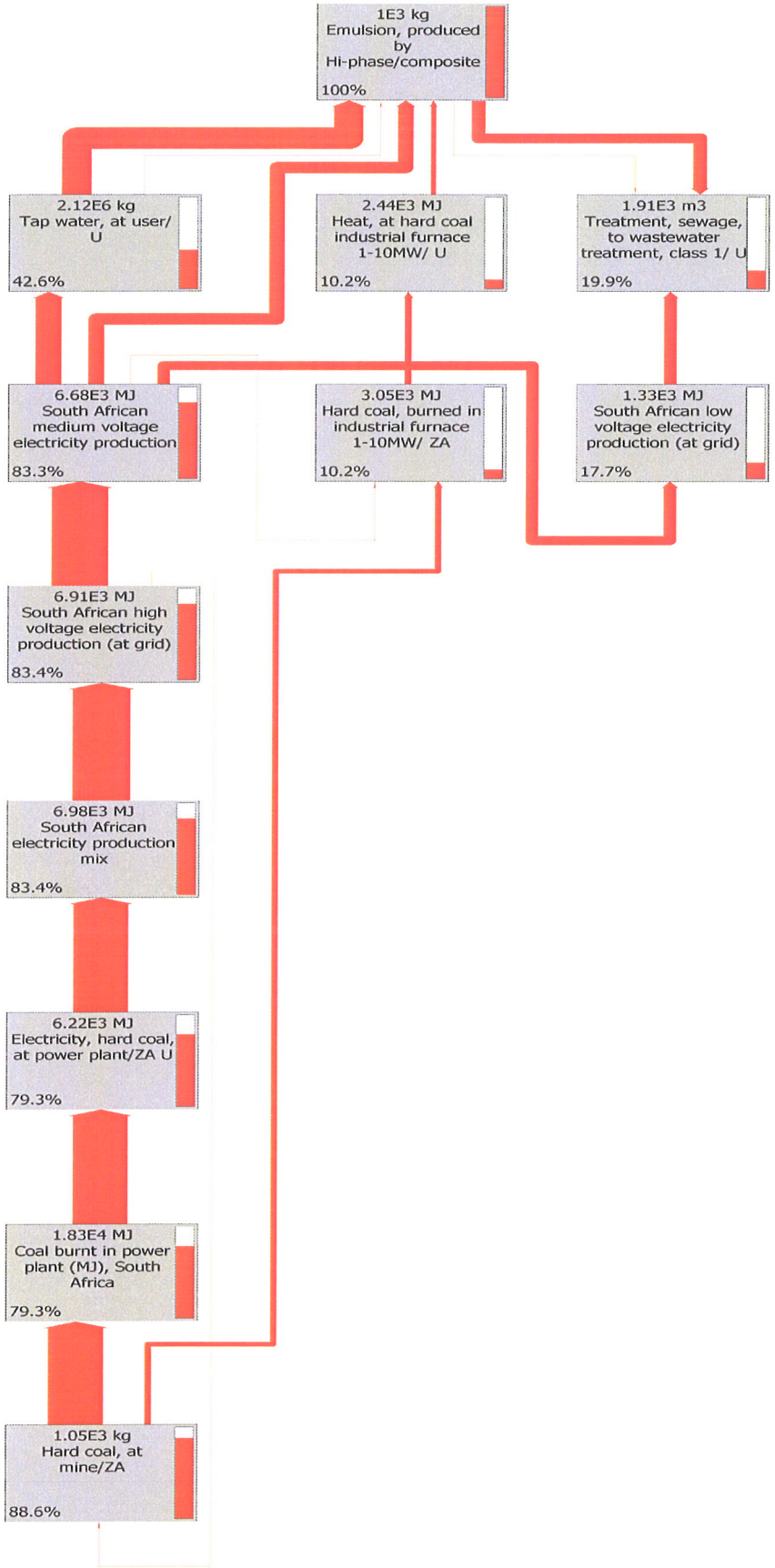
Appendix 13.10 Hi-phase/composite process using solid rosin: Ecosystem Quality



Appendix 13.11 Hi-phase/composite process using solid rosin: Climate Change



Appendix 13.12 Hi-phase/composite process using solid rosin: Resources



Appendix 14: IMPACT 2002+ damage category results per ton of emulsion produced for various model assumptions and parameter inputs

Damage category	*Unit*	*Base scenario*	*Water & electricity allocation by batch*	*Water variation* low	High	*Electricity variation* low	high	*Steam variation* low	high	*Steam calculation by batch*	*Cooling water evaporative loss : 50%*	*economic allocation in liquid rosin production*	*Including forestry in gum rosin production*
Aquapel process													
Human Health	DALY	0.0028	0.0041	0.0020	0.0036	0.0028	0.0029	0.0028	0.0029	0.0029	0.0022	-	-
Ecosystem Quality	PDF*m2*yr	9153	9888	5920	12386	9144	9162	9147	9159	9169	5631	-	-
Climate Change	kg CO2	2176	3559	1645	2706	2119	2232	2150	2202	2244	1946	-	-
Resources	MJ primary	35164	54691	28210	42119	34370	35959	34911	35418	35834	32552	-	-
Hi-phase/composite process using liquid rosin													
Human Health	DALY	0.0032	0.0031	0.0023	0.0041	0.0031	0.0032	0.0031	0.0032	0.0032	0.0026	0.0028	
Ecosystem Quality	PDF*m2*yr	9212	9160	5504	12919	9202	9221	9199	9225	9219	5690	8866	
Climate Change	kg CO2	2407	2303	1799	3015	2347	2468	2353	2462	2440	2177	2099	
Resources	MJ primary	31058	29582	23083	39034	30208	31909	30526	31591	31375	28447	27553	
Hi-phase/composite process using solid rosin													
Human Health	DALY	0.0030	0.0029	0.0020	0.0039	0.0029	0.0030	0.0029	0.0030	0.0029	0.0024	-	0.0030
Ecosystem Quality	PDF*m2*yr	8875	8824	5168	12583	8866	8885	8851	8899	8860	5354	-	17897
Climate Change	kg CO2	2283	2178	1674	2891	2222	2343	2183	2383	2215	2053	-	2283
Resources	MJ primary	29474	27998	21499	37450	28624	30324	28499	30449	28811	26862	-	29474

Appendix 15: Aquapel Process Qualitative Data

	Estimation of potential						Potential available	Weighting "Expert opinion"	Total Points Process	Total Points Cost	Comments (type, quantity, benchmarks etc.)
Input	(Eco) toxic problem materials	◉	none	○	small quantities	○	large quantities	no	-	-	
	Raw, auxiliary and operating materials	○	none	◉	small quantities	○	large quantities	1	1.5	1.5	
	Energy consumption	○	low	◉	moderate	○	high	1	1.5	1.5	Excess energy is used because there is no temperature control.
	Costs (input materials and energy)	○	low	◉	moderate	○	high	1	1.5		1.5
Waste / wastewater / emissions	Solid waste	○	none	◉	small quantities	○	large quantities	1	1.5	1.5	
	Special- (or hazardous) waste (e.g. acc. to Basel Convention)	◉	none	○	small quantities	○	large quantities	no	-	-	
	Wastewater	○	none	◉	small volumes	○	large volumes	1	1.5	1.5	
	Problem wastewater components	○	none	○	small quantities	◉	large quantities	2	1.5	3	Enzyme efficiency treatment plant is constructed because of high COD and BOD's
	Airborne emissions (gases, VOC's, dust, waste heat)	○	none	◉	small quantities	○	large quantities	1	1.5	1.5	
	Disposal or preparation costs (internal / external)	◉	low	○	moderate	○	high	no	-		-
Technology	Technology status	○	appropriate	◉	suitable for optimisation	○	unsuitable	1	1.5	1.5	No active temperature contrl at the control room.
	Level of automation	◉	appropriate	○	suitable for optimisation	○	unsuitable	no	-	-	Some valve should be automated for steam control.
	Faulty batches, scrap	◉	none	○	small quantities	○	large quantities	no	-	-	All faulty batches are reworked no waste are generated.
	Maintenance, servicing, cleaning	○	appropriate	◉	suitable for optimisation	○	unsuitable	1	1.5	1.5	Preventative maintenance plan is done once a month.
	Costs for maintenance, servicing, stoppages, scrap	○	low	◉	moderate	○	high	1	1.5		1.5
Level of optimisation of current process Expert opinion		○		○		○		◉		○	Chosen Weighting = 1.5
Results								Average of "process" points		1.7	Environmental CP potential: moderate (XX)
								Average of points for "cost"		1.5	Economic CP potential: moderate (XX)

Appendix 16: Rosin Process (Composite / Hiphase) Qualitative Data

	Estimation of potential						Potential available	Weighting "Expert opinion"	Total Points Process	Total Points Cost	Comments (type, quantity, benchmarks etc.)
Input	(Eco) toxic problem materials	○	none	◉	small quantities	○	large quantities	1	1	1	
	Raw, auxiliary and operating materials	○	none	◉	small quantities	○	large quantities	1	1	1	
	Energy consumption	○	low	○	moderate	◉	high	2	1	2	Excess energy is used because there is no active temperature conrol and as a result it exceeds the required temperature. So far no effort has been made to reduce
	Costs (input materials and energy)	○	low	○	moderate	◉	high	2	1		2
Waste / wastewater / emissions	Solid waste	◉	none	○	small quantities	○	large quantities	no	-	-	
	Special- (or hazardous) waste (e.g. acc. to Basel Convention)	◉	none	○	small quantities	○	large quantities	no	-	-	
	Wastewater	○	none	◉	small volumes	○	large volumes	1	1	1	
	Problem wastewater components	◉	none	○	small quantities	○	large quantities	no	-	-	
	Airborne emissions (gases, VOC's, dust, waste heat)	○	none	○	small quantities	◉	large quantities	2	1	2	More extractive fans are needed to the scrubber because at the moment its not efficient.
	Disposal or preparation costs (internal / external)	○	low	◉	moderate	○	high	1	1		1
Technology	Technology status	○	appropriate	◉	suitable for optimisation	○	unsuitable	1	1	1	More extractive fans are needed to the scrubber because at the moment its not efficient. The manner in which the drums are openned should be looked at.
	Level of automation	○	appropriate	◉	suitable for optimisation	○	unsuitable	1	1	1	At the moment the rosin is fed manually
	Faulty batches, scrap	◉	none	○	small quantities	○	large quantities	no	-	-	
	Maintenance, servicing, cleaning	○	appropriate	◉	suitable for optimisation	○	unsuitable	1	1	1	Steam leaks should be repaired to save energy.
	Costs for maintenance, servicing, stoppages, scrap	◉	low	○	moderate	○	high	no	-		-
Level of optimisation of current process Expert opinion		○		○		◉		○		Chosen Weighting = 1	
Results									Average of "process" points	1.3	Environmental CP potential: low (X)
									Average of points for "cost"	1.5	Economic CP potential: moderate (XX)

Appendix 17: Effluent Treatment Qualitative Data

	Estimation of potential						Potential available	Weighting "Expert opinion"	Total Points Process	Total Points Cost	Comments (type, quantity, benchmarks etc.)
Input	(Eco) toxic problem materials	○	none	○	small quantities	◉	large quantities	2	2	4	Enzyme efficiency treatment plant is being constucted.
	Raw, auxiliary and operating materials	○	none	◉	small quantities	○	large quantities	1	2	2	Caustic soda and Citri acid are used to control the pH to range between 7-8
	Energy consumption	◉	low	○	moderate	○	high	no	-	-	
	Costs (input materials and energy)	○	low	◉	moderate	○	high	1	2		2
Waste / wastewater / emissions	Solid waste	○	none	◉	small quantities	○	large quantities	1	2	2	Wastes are generated from the whole factory
	Special- (or hazardous) waste (e.g. acc. to Basel Convention)	○	none	◉	small quantities	○	large quantities	1	2	2	
	Wastewater	○	none	○	small volumes	◉	large volumes	2	2	4	
	Problem wastewater components	○	none	○	small quantities	◉	large quantities	2	2	4	Level of COD and BOD are high.
	Airborne emissions (gases, VOC's, dust, waste heat)	○	none	◉	small quantities	○	large quantities	1	2	2	Emmissions are generated by the pilot plants and the rosin.
	Disposal or preparation costs (internal / external)	○	low	○	moderate	◉	high	2	2		4
Technology	Technology status	○	appropriate	◉	suitable for optimisation	○	unsuitable	1	2	2	Busy installing the water treatment plant.
	Level of automation	○	appropriate	◉	suitable for optimisation	○	unsuitable	1	2	2	The automation will be instituted.
	Faulty batches, scrap	◉	none	○	small quantities	○	large quantities	no	-	-	
	Maintenance, servicing, cleaning	○	appropriate	◉	suitable for optimisation	○	unsuitable	1	2	2	Once the teratment plant start running, it can be assessed.
	Costs for maintenance, servicing, stoppages, scrap	◉	low	○	moderate	○	high	no	-		-
Level of optimisation of current process Expert opinion		○		○		○		○		◉	Chosen Weighting = 2
Results									Average of "process" points	2.6	Environmental CP potential: moderate (XX)
									Average of points for "cost"	3.0	Economic CP potential: high (XXX)

Appendix 18: Cooling Water System Qualitative Data

Estimation of potential									Potential available	Weighting "Expert opinion"	Total Points Process	Total Points Cost	Comments (type, quantity, benchmarks etc.)
Input	(Eco) toxic problem materials	◉	none	○	small quantities	○	large quantities		no	-	-		
	Raw, auxiliary and operating materials	◉	none	○	small quantities	○	large quantities		no	-	-		
	Energy consumption	○	low	◉	moderate	○	high		1	1.5	1.5		
	Costs (input materials and energy)	○	low	◉	moderate	○	high		1	1.5		1.5	
Waste / wastewater / emissions	Solid waste	◉	none	○	small quantities	○	large quantities		no	-	-		
	Special- (or hazardous) waste (e.g. acc. to Basel Convention)	◉	none	○	small quantities	○	large quantities		no	-	-		
	Wastewater	○	none	◉	small volumes	○	large volumes		1	1.5	1.5		Overflow condensate should be recovered.
	Problem wastewater components	◉	none	○	small quantities	○	large quantities		no	-	-		
	Airborne emissions (gases, VOC's, dust, waste heat)	◉	none	○	small quantities	○	large quantities		no	-	-		
	Disposal or preparation costs (internal / external)	◉	low	○	moderate	○	high		no	-		-	
Technology	Technology status	◉	appropriate	○	suitable for optimisation	○	unsuitable		no	-	-		
	Level of automation	◉	appropriate	○	suitable for optimisation	○	unsuitable		no	-	-		
	Faulty batches, scrap	◉	none	○	small quantities	○	large quantities		no	-	-		
	Maintenance, servicing, cleaning	◉	appropriate	○	suitable for optimisation	○	unsuitable		no	-	-		
	Costs for maintenance, servicing, stoppages, scrap	◉	low	○	moderate	○	high		no	-		-	
Level of optimisation of current process Expert opinion		○		○		○		◉	○	Chosen Weighting = 1.5			
Results										Average of "process" points	1.5		Environmental CP potential: moderate (XX)
										Average of points for "cost"		1.5	Economic CP potential: moderate (XX)

Appendix 19: Steam Process Qualitative Data

	Estimation of potential									Potential available	Weighting "Expert opinion"	Total Points Process	Total Points Cost	Comments (type, capacity, observations etc.)
Heat distribution system: piping, fittings, insulation	Technology status, condensate or hot water recovery	○	suitable	◉	candidate for optimisation	○	unsuitable			1	1	1		Repairs for steam leaks should be done to save energy.
	Maintenance of insulation, fixtures	○	good, preventive	◉	candidate for optimisation	○	unsuitable			1	1	1		
	Losses in heating system (leaks, long internal transport routes, insulation)	○	low	◉	moderate	○	high			1	1		1	They have installed a monitoring system for steam from suppling company
	Level of optimisation of heating system Expert opinion	○		○		◉		○		Chosen Weighting = 1				
Boiler 1	Technology status, use of alternative energy sources	◉	suitable	○	candidate for optimisation	○	unsuitable			no	-	-		The steam used is from supplying company because they don't have their own boilers. It is convinient for them because they think it is cheaper that way.
	Boiler servicing, maintenance	◉	good, preventive	○	candidate for optimisation	○	unsuitable			no	-	-		
	Losses through inefficient operation or unsuitable technology	◉	low	○	moderate	○	high			no	-		-	
	Level of optimisation of boiler 1 Expert opinion	○		○		◉		○		Chosen Weighting = 1				
Boiler 2	Technology status, use of alternative energy sources	◉	suitable	○	candidate for optimisation	○	unsuitable			no	-	-		
	Boiler servicing, maintenance	◉	good, preventive	○	candidate for optimisation	○	unsuitable			no	-	-		
	Losses through inefficient operation or unsuitable technology	◉	low	○	moderate	○	high			no	-		-	
	Level of optimisation of boiler 2 Expert opinion	○		○		◉		○		Chosen Weighting = 1				
Boiler 3	Technology status, use of alternative energy sources	◉	suitable	○	candidate for optimisation	○	unsuitable			no	-	-		
	Boiler servicing, maintenance	◉	good, preventive	○	candidate for optimisation	○	unsuitable			no	-	-		
	Losses through inefficient operation or unsuitable technology	◉	low	○	moderate	○	high			no	-		-	
	Level of optimisation of boiler 3 Expert opinion	○		○		◉		○		Chosen Weighting = 1				
	Results										Average of "process" points	1.0		Environmental CP potential: low (X)
											Average of points for "cost"		1.0	Economic CP potential: low (X)

Appendix 20: Energy Management Qualitative Data

Estimation of potential										Potential available	Weighting "Expert opinion"	Total Points Process	Total Points Cost	Comments
Process-energy consumption (compared to energy consumption for indoor heating or air conditioning)	◉	low	○	moderate	○	high				no	-	-		Steam management system in terms of a meter should be installed.
Energy management system (energy accounting, capacity management)	○	introduced	◉	partially introduced	○	none				1	2		2	
Use of alternative energy sources, waste heat recovery, heat pumps, combined heat and power generation, district heating or cooling, absorption type refrigerating machine	○	introduced	○	partially available	◉	none				2	2	4		
Level of optimisation of energy management system Expert opinion	○		○		○		○		◉	Chosen Weighting =2				
Results										Average of "process" points		4.0		Environmental CP potential: high (XXX)
										Average of points for "cost"			2.0	Economic CP potential: moderate (XX)

- *Greenhouse effect:* the anticipated temperature rise as a result of the increasing concentration of gases that restrict heat radiation by the Earth.

- *Ozone layer depletion:* the increase in ultraviolet radiation on Earth caused by high altitude decomposition of the ozone layer.

- *Acidification:* degradation of forests in particular by, for example, acid rain.

- *Eutrophication:* the disappearance of rare plants that grow in poor soils, as a result of the emission of substances that have the effect of a fertiliser and the changes in aquatic ecosystems.

- *Smog:* the problems for people with weak airways (asthma patients) caused by the high concentration of low-level ozone or by dust and sulphur compounds.

- *Toxic substances:* toxic substances other than as described, e.g. heavy metals, carcinogenic substances and pesticides.