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Applied Evaluation for Life Cycle Impact Assessment Methodologies in the Medical Industry

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APPLIED EVALUATION FOR LIFE CYCLE IMPACT ASSESSMENT METHODOLOGIES IN THE MEDICAL INDUSTRY

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Dedication

To my family, especially my grandmother Maria de la Luz Ramos

APPLIED EVALUATION FOR LIFE CYCLE IMPACT ASSESSMENT METHODOLOGIES IN THE MEDICAL INDUSTRY

by

AARON ARTURO MARTINEZ, B.S. Industrial Engineering

THESIS

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Abstract

In the present thesis, a comparative evaluation using different Life Cycle Impact Assessment (LCIA) Methodologies is presented; the study is performed considering the LCIA of ChloraPrep 26 mL Hi-Lite Applicator produced in a local manufacturing company. The focus of the research is to analyze the different aspects such as: characterization, classification and normalization; that each of the LCIA methodologies evaluate and are used for a policy regulations and sustainable development. The evaluation will determine which aspects could be used depending on the Life Cycle Inventory, since limited information is available if not using softwares, such as SimaPro or GaBi, to perform a Life Cycle Analysis. Since most of the methodologies are European based, the study will reflect the difference between the European and two U.S. developed methodologies.

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1. Introduction

As the world's population continues to grow and living standards rise, the demand for natural resources increases, as well as the waste generated. Our capacity to assimilate waste is outgrown by our waste production rate. The regeneration of renewable natural resources does not keep up with the waste production, while non-renewable resources are depleted indiscriminately.

Earth's climate change is changing; temperatures are rising, snow and rainfall patterns are shifting, and more extreme climate events are already affecting society and ecosystems. Scientists are confident that many of the observed changes in the climate can be linked to the increase in greenhouse gases in the atmosphere (EPA, 2012). Climate change is one of the major challenges of our time and adds considerable stress to our societies and to the environment (Zahedi, 2012). Understanding climate science and raising public awareness of the Earth's changing climate may alleviate the problematic situation by reducing the amount of pollution generated by human activities.

Government, companies and society can make sound policy, technology, and investment choices that reduce emissions and drive sustainable social and economic development. Collecting greenhouse gas emissions enables the identification of areas of opportunity t o reduce pollution, and increase the efficient utilization of the natural resources. Moving towards low carbon societies can help reduce greenhouse gas emissions, improving health and well-being.

The main greenhouse gas emissions are methane, nitrous oxide and carbon dioxide. Although carbon dioxide has the larger concentrations in the atmosphere, methane and nitrous dioxide have the most impact in the environment. Climate change is the outcome of the greenhouse effect, which is the amount of heat retained by the Earth's atmosphere caused by high concentrations of greenhouse gases. In order to evaluate and develop strategies to protect our natural environment and make our communities more attractive, economically stronger, and more socially diverse, there are decision making tools and techniques that can be used to make more informed decisions through a better understanding of human health and environmental impacts of products, processes and activities.

1.1 Life Cycle Analysis

Industrial enterprises are realizing that the impact their products have on the environment is not only inherent to the manufacturing processes. A product's impact on the environment starts when it is conceptualized (design phase) and ends at the ultimate disposal, which can be landfill or recycling, after its useful life.

Life Cycle Analysis (LCA) is a "cradle-to-grave" approach to evaluate any type of system; from industrial systems to single products. The analysis starts when raw materials are extracted from earth and ends when the product returns to earth (landfills/recycling). There is another LCA approach: "The fence line", which consists in studying the impacts associated with the product on site and disregards the off-site functions. It provides insights into the operations at the site and the impact that may occur. The information obtained from the analysis can then be used to minimize the impact that materials or processes has on the environment. The study compiles the inputs (energy, material, etc.) and outputs (energy, waste, products) from each stage of a product's life to assess the total environmental impact.

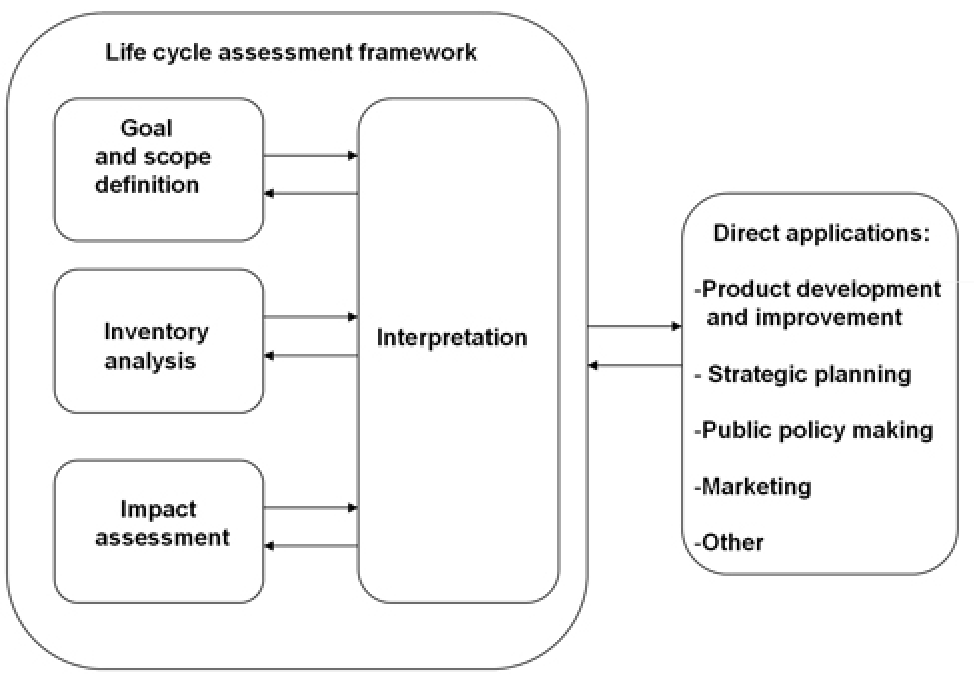

Figure 1 Life Cycle Assessment Framework according to ISO 14040. (**ISO 14040, 1997**)

The LCA is a systematic approach consisting of four components:

1. Goal definition and Scope
2. Inventory analysis
3. Impact assessment
4. Interpretation

1.1.1 Goal and Scope definition

This section of the LCA defines and describes the intended application and arguments to conduct the LCA. It should also state to whom the results are going to be reported. As the goal is defined, so is the scope for the analysis, since the boundaries to conduct the study will be properly defined.

In the analysis, it is not feasible to include every aspect of the product's life. Therefore, the scope will set the functions of the system and the functional units that will describe the methodological choices, assumptions and limitations, in which the study is based (Finnveden, Johansson, Lind, & Asa, 2000). The scope defines which unit processes are going to be included in the LCA.

In this phase, it is important to identify the type of information that is needed to add value to the decision-making process, how accurate the results should be, and the type of result interpretation in order to be meaningful and usable.

1.1.2 Life Cycle Inventory

Through this phase a quantitative catalog of relevant inputs and outputs from the product will be provided. Therefore, the boundaries of the LCA will set the product's life stages where the information should be collected and analyzed. Data can be obtained from scientific literature, published data files, industry or government records (Finnveden, Johansson, Lind, & Asa, 2000). If quantitative information is not available, it is possible to estimate data from qualitative sources.

The level of accuracy and detail of the data can assist in comparing products or processes and determining the environmental factors of material selection. As a result, the inventory will provide the amounts of outputs (material waste, pollutants) at each stage of the product's life. There are four phases on a life cycle inventory (Curran, 2006):

1. Developing a flow diagram of the processes being evaluated - Maps the inputs and outputs to a processes or system, within the boundaries defined on the Scope of the LCA.
2. Develop a Collection Data Plan – The level of data accuracy required is ensured by the plan.
3. Data Collection – involves research, site-visits, direct contact with experts, or LCA software.
4. Evaluate and report results – Is important to describe the methodology used in the analysis.

1.1.3 Life Cycle Impact Assessment

The Life Cycle Impact Assessment (LCIA) phase of a LCA is the evaluation of potential human health and environmental impacts of the environmental resources and releases identified during the LCI (Curran, 2006). It attempts to establish a relationship between the product and its ecological and human health effects.

The LCIA provides a more meaningful basis to make comparisons of stressors that lead to an impact. To quantify and model the contributions of different inputs and emissions, there are impact categories, which are science-based characterization factors, that can calculate the impacts each environmental releases (Carbon dioxide, Methane, etc.) has on problems such as global warming.

There are two types of analysis when modeling a LCIA for the effects of the stressors: Midpoint and Endpoint modeling. Midpoint modeling can minimize assumptions and value choices, reflect a higher level of societal consensus, and be more comprehensive than model coverage for endpoint estimation (Bare J. , Norris, Pennington, & McKone, 2003).

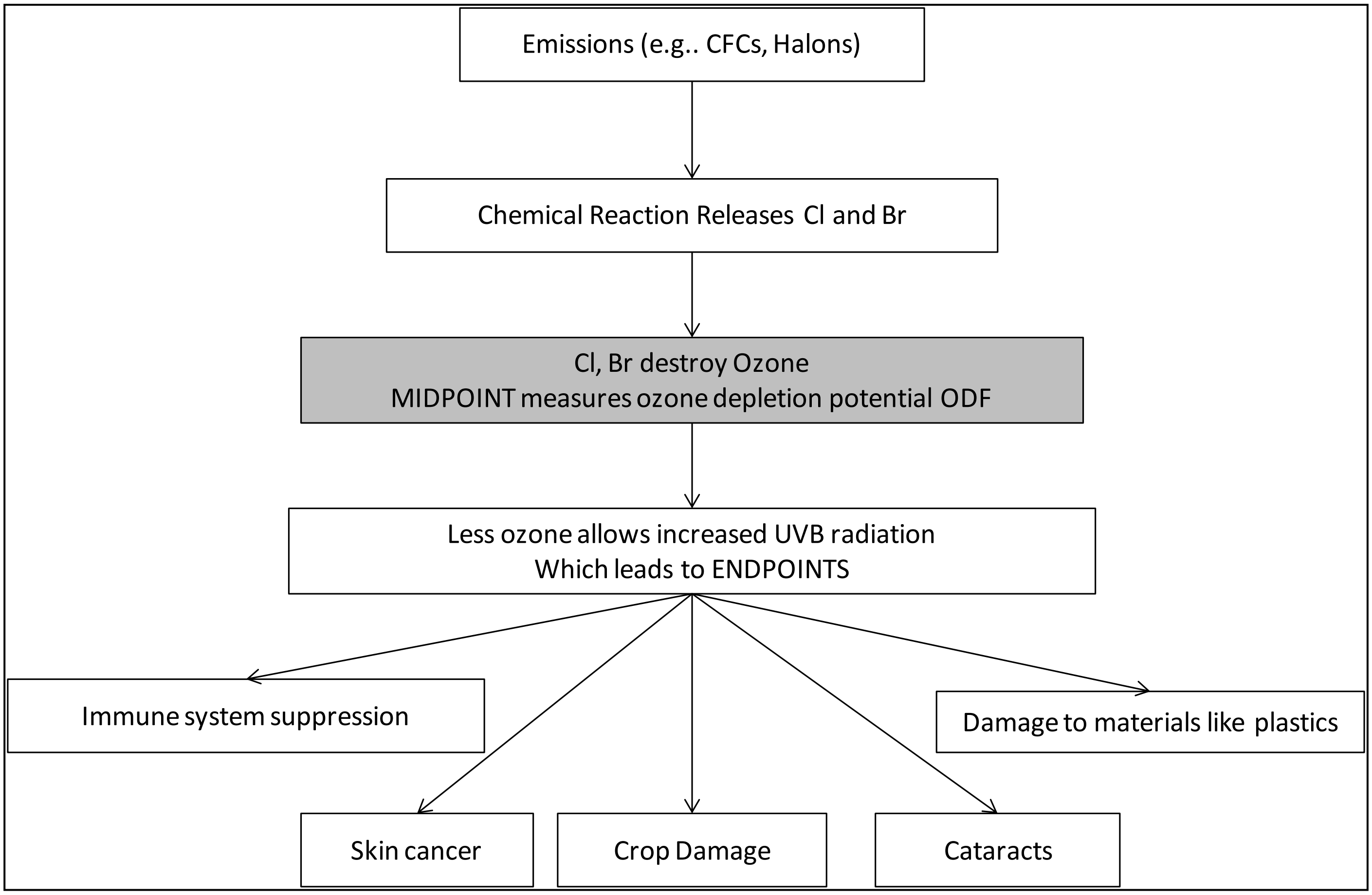

Figure 2 Midpoint versus Endpoint Modeling. (Curran, 2006)

The International Standard Organization developed the standard ISO 14042:2006 entitled Environmental Management – Life Cycle Assessment – Principles and Framework, which describes steps for an LCIA, being the first three mandatory.

1. Selection and Definition of Impact Categories
2. Classification
3. Characterization
4. Normalization
5. Grouping
6. Weighting
7. Evaluation and Reporting LCIA Results.

LCIA defines impacts as consequences caused by the inputs and outputs for a system on human health, ecological health, and resource depletion. When an LCI is done, the results should be organized into impact categories. There are items that contribute to two or more different categories, which should follow the following rule from ISO 14042:2006:

- Partition a representative portion of the LCI results to the impact categories to which they contribute. This is typically allowed in cases when the effects are dependent on each other.
- Assign all LCI results to all impact categories to which they contribute. This is typically allowed when the effects are independent of each other.

As the items from LCI are allocated into the different categories (see Table 1), the items are characterized into representative indicators of impacts to human and environmental health to directly compare the results within each impact category.

1.1.4 Life Cycle Interpretation

Life Cycle Interpretation is a systemic technique to identify, quantify, check, and evaluate information from the results of the LCI and LCIA (Curran, 2006) in a manner that increases the comprehension of the results without oversimplifying them.

ISO has defined the following two objectives of life cycle interpretation:

1. Analyze results, reach conclusions, explain limitations, and provide recommendations based on the findings of the preceding phases of the LCA, and to report the results of the life cycle interpretation in a transparent manner.
2. Provide a readily understandable, complete, and consistent presentation of the results of an LCA study, in accordance with the goal and scope of the study (14043, 1998).

Conducting an LCA is necessary to state the assumptions clearly, engineered estimates, and provide conclusion to inform decision makers with a particular type of information associating human and environmental health with each product or process.

Key steps to interpret the results of the LCA:

1. Identification of the Significant Issues based on the LCI and LCIA.
2. Evaluation which considers Completeness, Sensitivity, and Consistency Checks.
3. Conclusions, Recommendations, and Reporting.

Table 1 Commonly used Life Cycle Impact Categories (14040, 1997)

Impact Category	**Scale**	**Examples of LCI Data (i.e. classification)**	**Common Possible Characterization Factor**	**Descrption of Characterization Factor**
Global Warming	Global	Carbon Dioxide (CO2) Nitrogen Dioxide (NO2) Methane (CH4) Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Methyl Biomide (CH3BR3)	Global Warming Potential	Converts LCI data to carbon dioxide (CO2) equivalents Note: global warming potentials can be 50, 100, or 500 year potentials.
Stratospheric Ozone Depletion	Global	Nitrogen Dioxide (NO2) Methane (CH4) Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Methyl Biomide (CH3BR3) Halons	Ozone Depleting Potential	Converts LCI data to trichlorofluoromethane (CFC-11) equivalents.
Acidification	Regional Local	Sulfur Oxides (Sox) Nitrogen Oxides (Nox) Hydrochloric Acid (HCL) Hydroflouric Acid (HF) Ammonia (NH4)	Acidification Potential	Converts LCI data to hydrogen (H+) ion equivalents
Eutrophication	Local	Phosphate (PO4) Nitrogen Oxide (NO) Nitrogen Dioxide (NO2) Nitrates Ammonia (NH4)	Eutrophication Potential	Converts LCI data to phosphate (PO4) equivalents
Photochemical Smog	Local	Non-methane hydrocarbon (NMHC)	Photochemical Oxidant Creation Potential	Converts LCI data to ethane (C2H6) equivalents

Terrestrial Toxicity	Local	Toxic chemicals with a reported lethal concentrations to rodents	LC 50	Converts LC50 data to equivalents; uses multimedia modeling, exposure pathways
Aquatic Toxicity	Local	Toxic chemicals with a reported lethal concentrations to fish	LC 50	Converts LC50 data to equivalents; uses multimedia modeling, exposure pathways
Human Health	Global Regional Local	Total releases to air, water, and soil	LC 50	Converts LC50 data to equivalents; uses multimedia modeling, exposure pathways
Resource Depletion	Global Regional Local	Quantity of minerals used Quantity of fossil fuels used	Resource Depletion Potential	Converts LCI data to a ratio of quantity of resource used versus quantity of resource left in reserve
Land Use	Global Regional Local	Quantity disposed of in a landfill or other land modidications	Land Availability	Converts mass of solid waste into volume using an estimated density
Water Use	Regional Local	Water used or consumed	Water Shortage Potential	Converts LCI data to a ratio of quantity of water used versus quantity of resource left in reserve

1.2 THESIS OBJECTIVE

The objective of this research to compare Life Cycle Impact Assessment Methodologies, using a real life cycle analysis for a ChloraPrep 26 mL Hi-Lite Applicator from a local company, in order to analyze how these impact assessment methodologies differ from each other, the background from which they are developed, and the interpretation for the results for each methodology. Chapter 1 introduces the Life Cycle Analysis and explains the systematic steps to perform an analysis. The chapter 2 is a literature research of the different methodologies, Chapter 3 is the case study, and Chapter 4 final conclusions.

2. Life Cycle Impact Assessment Methodologies

A large number of methods and tools for describing environmental aspects have been developed which can be used in different types of decision contexts (Finnveden, Johansson, Lind, & Asa, 2000). A Life Cycle Impact Assessment (LCIA) studies the environmental aspects and potentials impacts throughout a product's life from raw material acquisition through production, use and disposal (14043, 1998). The LCIA is a phase of the LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system (14040, 1997)

The first phase for a LCIA is to select a manageable number of impact categories of resource use and environmental impacts, indicators for the categories and models to quantify the contribution of different inputs and emissions to the impact categories. The second phase is an assignment of the inventory data to the impact categories. The third phase is a quantification of the contributions to the chosen impact categories. The fourth phase is the normalization to relate the magnitude of the impacts in the different categories to reference values. The fifth phase is weighing, this phase aims at converting and aggregating results across impact categories resulting in a single result.

Table 2 Default list of impact categories for life cycle impact assessment **(Udo de Haes, et al., 1999)**

Input related categories
1. Abiotic resources (deposits, funds, flows)
2. Biotic resources (funds)
3. Land
Output related categories
4. Global warming
5. Depletion of stratospheric ozone
6. Human toxicological impacts
7. Ecotoxicological impacts
8. Photo-oxidant formation
9. Acidification
10. Eutrophication (incl. BOD and heat)
11. Odour
12. Noise
13. Radiation
14. Casualties
Pro memoria: Flows not followed to the system boundary
Input related
Output related

Different methods have been developed to evaluate the impact of environmental emissions, such as Eco-Indicator 95, Eco-Indicator 99, Traci and IMPACT 2002+. The difference between these methodologies is explained in the following sections along with the case study.

2.1 ECO-INDICATOR 95

During the developing phase of new products (Design phase) different alternatives are generated that will be analyzed by the designers to choose the best available design. To become an environmentally conscious company, the environmental aspects of the product development must be included in the design and analysis process. The Eco-indicator is a tool which can be used in the search for more environmentally-friendly design alternatives and is intended for internal use only (PRe Consultants, 1996). The use of Eco-indicators purpose is solely to design more environmental-friendly products used only within the company.

The Eco-indicator of a product is a number that indicates the environmental impact based on data from the life cycle assessment. The following demarcation has been chosen for the Eco-indicator method: "Environmental effects that damage ecosystems or human health on a European scale" (PRe Consultants, 1996).

The Eco-indicator is based on the following effects:

- Greenhouse effect. The expected rise on temperature caused by the concentration of gases.
- Ozone layer depletion. The increase in ultraviolet radiation on earth.
- Acidification. Degradation of forests.
- Eutrophication. The disappearance of rare plants as a result of emission of substances that have a fertilizer effect.
- Smog. Population health diseases caused by high concentrations of low level ozone.
- Toxic Substances.

The Eco-indicator is one of the first weighing systems developed in the world. This method has been used by several authors for different applications, for example the agricultural production

(Brentrup, Kusters, Kuhlmann, & Lammel, 2001), water supply (Mohaptra, Siebel, Van der Hoek, & Groot, 2002), and database for a software (Consultants, 2008).

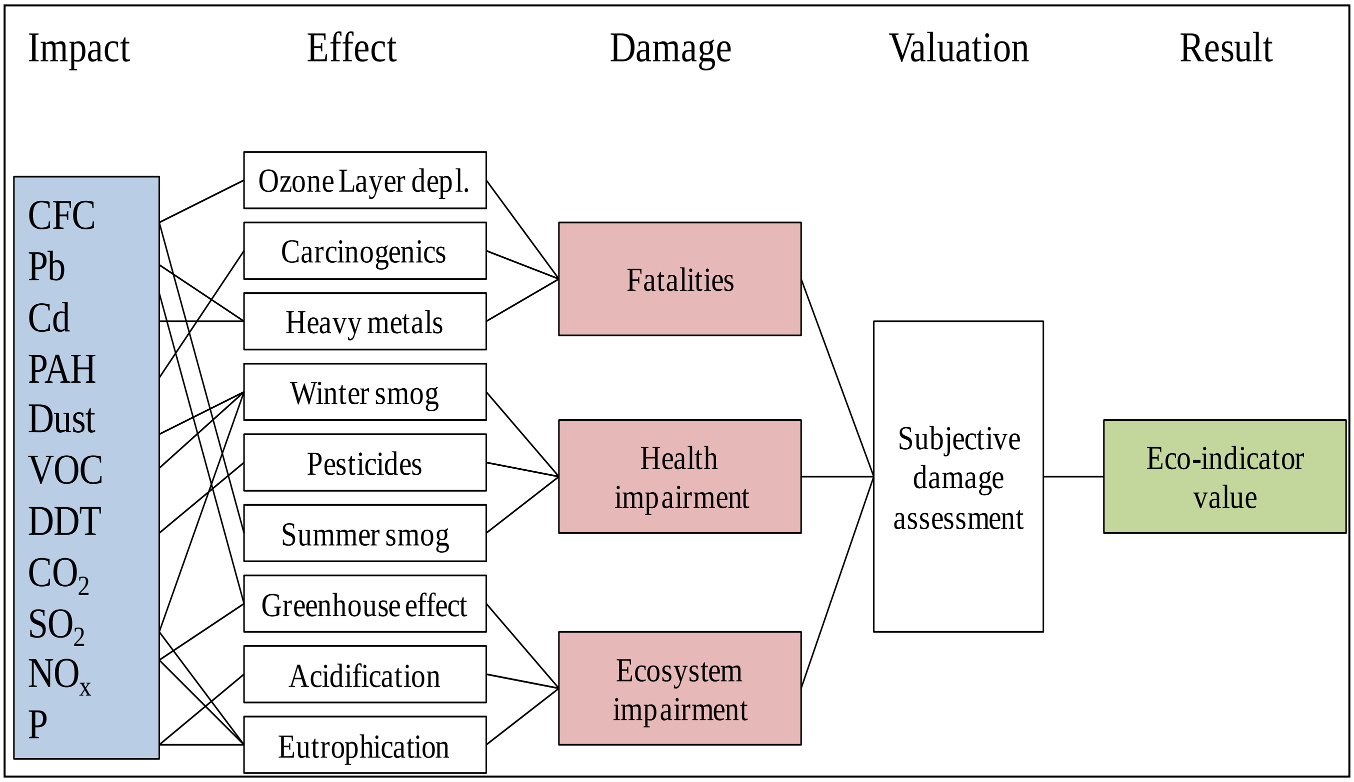

Figure 3 Eco-indicator weighting principle **(PRe Consultants, 1996)**.

2.1.1 Description of Eco-indicators

Eco-indicator values are available for:

Production of materials

The processes from extraction of raw materials to the last production stage determine the indicator. Transportation is also included as long as it is within the production chain. For example, a research study "Aggregating and evaluating the results of different Environmental Impact Assessment methods" (Daniel, Tsoulfas, Pappis, & Rachaniotis, 2004) applied the Eco-indicator 95 to evaluate two alternative end-of-life scenarios for lead-acid batteries, where the first scenario deals with the flow of used products from consumers to recovery facilities, and the second scenario deals with the disposal chain (landfills).

Treatment Process

Relate to the emissions from the process itself and emissions from the energy generation processes that are necessary. Dickinson (2002) compared the Eco-Indicator 95 against the Sustaianability Target Method in order to evaluate the production of common materials related to electronics products and the generation of electrical energy using various fossil fuels sources.

Transport

Transportation processes include the impact emissions caused by the extraction and production of fuel and the generation of energy from fuel during transportation. All units are based on European data.

The unit = 1000 kg of goods over 1 km.

Energy

Energy refers to the extraction and production of fuels and to energy generation. An Eco-indicator is determined for high-voltage electricity for industrial process, and low-voltage for household. Finnveden et al.(2003) aimed to examine how Strategic Environmental Assessment (SEA), which is a procedural tool to facilitate and systematic consideration of potential environmental impacts in strategic decision making, could be used within the SEA process in the following steps: Scenario Analysis, Environmental Analysis and Evaluation, Life Cycle Assessment, and Risk Assesment.

Waste Processing and Recycling

The end-of-life phase does not have a unique process. The products may end in landfills or being recycled. Two different scenarios were developed in order to assume which waste processing is most likely:

- Household waste. Materials such as glass, paper and compostable waste are collected and recycled separately. It is based on Dutch population.
- Municipal waste. Is modeled for waste in the Netherlands.
- Incineration. Is assumed that is carried out in modern plant with high quality scrubbing system.

- Landfill disposal. Is based on modern landfill sites with water purification and good seals.
- Recycling. It is assumed that material is sorted by type (material).

In the work "Life Cycle Assessments of Energy from Solid Waste" (Finnveden, Johansson, Lind, & Asa, 2000), they evaluate different strategies for treatment of solid waste to identify advantages and disadvantages, as well to identify critical factors in the systems, such as: landfilling, incineration, recycling, digestion and composting.

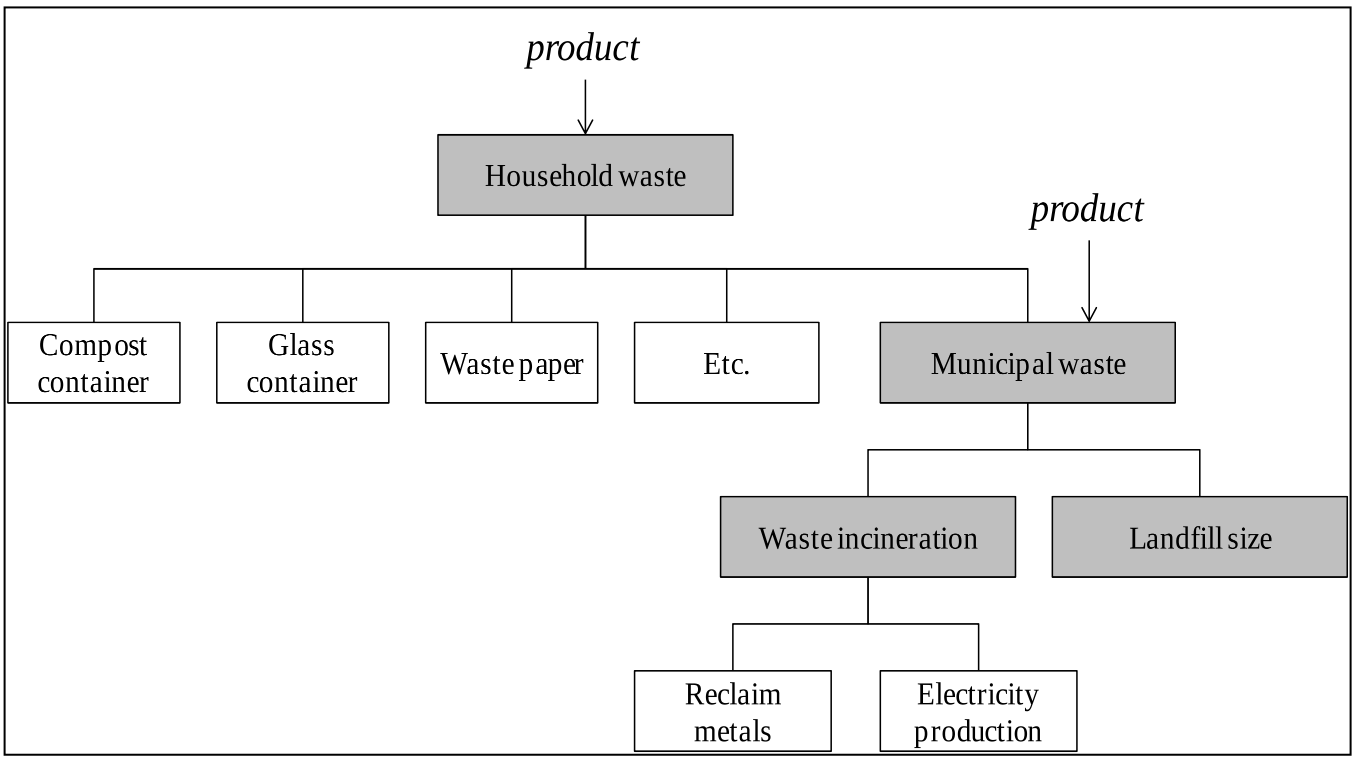

Figure 4 Waste Scenarios (PRe Consultants, 1996)

2.1.2 Example of Indicator's list and its application

The following steps should be followed to ensure the correct application of the Eco-indicator:

1. Establish the purpose of the Eco-indicator calculation. Describe the product, the level of accuracy required.
2. Define the Life Cycle (Scope).

3. Life Cycle Inventory, quantify the materials and processes (Functional Unit).
4. Fill the form. This point can be substituted if using software such as GaBi that calculates automatically.
5. Interpretation.

The following are examples of lists of Eco-indicator values, followed by a spread sheet to make calculations:

Transport (in milipoints)		
	Indicator	Description
Truck (28 Ton)	**0.34**	per ton kilometre, 60% loading. European average
Truck (75 m^3)	**0.13**	per m3 km, 60% loading. European average
Train	**0.043**	per ton kilometre. European average for diesel and electric traction
Container ship	**0.056**	per ton kilometre, fast ship, with relatively high fuel consumption
Aircraft (continental)	**1.7**	per kg, with continental flights the distance is not relevant
Aircraft (intercontinental)	**0.81**	per ton kilometre

Production of Energy (in milipoints)		
	Indicator	Description
Electricity high voltage	**0.57**	per kWh, for industrial use
Electricity low voltage	**0.67**	per kWh, for consumer use (230 v)
Heat from gas (MJ)	**0.063**	per MJ heat
Heat from oil (MJ)	**0.15**	per MJ heat
Mechanical (diesel, MJ)	**0.17**	per MJ mechanical energy from a diesel engine

Figure 5 Eco-indicator Value Table (PRe Consultants, 1996).

Product or component		Project	
Date		Author	
Notes and conclusions			
Production			
Materials, processing, transport and extra energy			
Material or process	amount	Indicator	result
Total			
Use			
Materials, processing, transport and extra energy			
Material or process	amount	Indicator	result
Total			

Figure 6 Eco-indicator Spread sheet calculator (PRe Consultants, 1996)

2.2 ECO-INDICATOR 99

Sustainable manufacturing and consumption is achievable if all the society members take their own responsibility by taking into account the environment in each decision making process. The Netherlands developed a set of policy instruments under the label of Integrated Product Policy (IPP).

The main frame of IPP is the introduction of Product Oriented Environmental Management System (POEM) concerted in an effort between the industry and the Deutsch government. The objective is to establish a systematic drive for continuous improvement of the life cycle environmental performance of products within all sorts of enterprises by integrating environmental aspects in strategic management decisions (Housing, 2000).

The LCA is a tool to assess the environmental performance of a product, but is time consuming and costly. The results of an LCA are hard to interpret since they are not straightforward when comparing one product or material over an alternative one. The results of an LCA are weighted in some methodologies for the easiness of the interpretation. The Eco-indicator 95 proved to be a powerful tool

because of its weighing method, which provided understandable and user-friendly units called Eco-indicators for the interpretation of the LCA results.

The new Eco-indicator 99 has a different weighing system because the Eco-indicator 95 used the Distance-to-Target approach. This method is criticized because it did not define clearly sustainable target levels, by introducing a damage function approach. The damage function approach is defined as the relation between the environmental impact and its damage to human health or ecosystem.

The Eco-indicator 99 has been used to analyze the water supply (Mohaptra, Siebel, Van der Hoek, & Groot, 2002), the impact of pesticides on human health and ecosystems (Marrgini, Rossier, & Jolliet, 2002), and in the manufacturing industry in South Africa (Brent & Hietkamps, 2002).

2.2.1 Differences with Eco-indicator 95

Eco-indicator 99 is an improved version of Eco-indicator 95, it improves the methodology to calculate the indicators and it expands the lists of indicators. It also does not include the Distance to Target principle and instead it developed the Damage approach. The following lists improvements made in Eco-indicator 99 (Housing, 2000):

- Much better and more explicit procedure for the weighting between the damage categories.
- Better description and definition of the damage models.
- Thorough description and specification of the uncertainties and assumptions,
- Inclusion of the fate (dispersion and degradation) of emissions in the environment.
- Wider range of emissions and effects.

The Eco-indicator 95 and Eco-indicator 99 values are not compatible.

2.2.2 Limitations

The standard Eco-indicator values are not intended for use in the environmental marketing or environmental labeling. Is for internal use only, meaning results cannot be proved in public when comparing products.

The Eco-indicator values are not intended to be used as an instrument for the Government to set standards and/or policy guidelines.

2.2.3 ISO and the Unit of Eco-indicators

The Eco-indicator methodology that calculates the standard values conforms well to the standard ISO 14042. The only difference relies is that Eco-indicator is used for internal use, while ISO 14042 discloses the comparative evaluations to the public.

The Eco-indicator values are dimensionless figures and the absolute value of the points are not relevant as the main purpose is to compare differences between products or components. The scale is that the value of 1 pt is representative for 1/1000 of the yearly environmental load of one average European inhabitant (Housing, 2000).

2.2.4 Similarities

As in the Eco-indicator 95, the values are available for:

- Materials
- Production processes
- Transport processes
- Energy generation processes
- Disposal scenarios

To ensure the correct application of the Eco-indicator the following steps should be followed:

- Establish the purpose of the Eco-indicator calculation
- Define the life cycle
- Quantify materials and processes
- Fill the form as in the Eco-indicator 95.
- Interpret results

2.2.5 Eco-indicator 99 methodology

In order to calculate the Eco-indicator score, the following steps should be followed:

1. Inventory of all relevant emissions, resource extractions and land-use in all processes that form the life cycle of a product.
2. Calculation of the damages these flows cause to Human health, Ecosystem quality and Resources.

3. Weighing of these three damage categories.

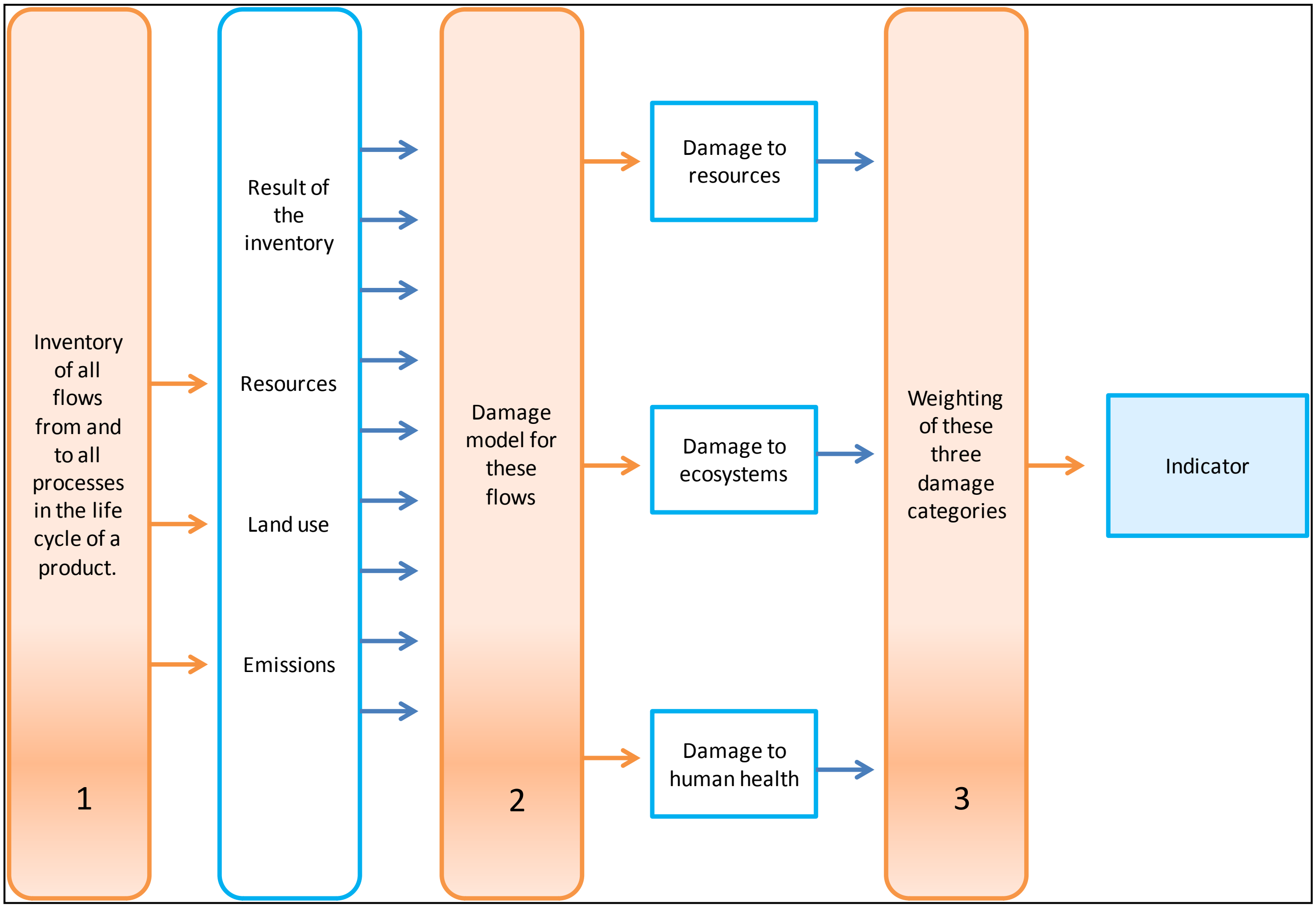

Figure 7 Calculation procedure for Eco-indicators (Housing, 2000).

2.2.6 Weighting

In the traditional LCA the emissions and resource extractions are expressed in 10 or more impact categories. Such high number of impact categories makes the weighting process difficult and sometimes meaningless without knowing the effects associated with these impact categories.

The Eco-indicator 99 does not weights the impact categories but the different types of damage that are caused by these impact categories. Moreover, it limits to three the damages to be assessed, which are the following:

1. Damage to Human Health. Expressed as the number of year life lost and the number of years lived disabled.
2. Damage to Ecosystem. Expressed as the number of species lost over a certain area in a certain time.
3. Damage to Resources. Expressed as the surplus energy needed for future extractions of minerals and fossil fuels.

2.2.7 Damage Model

To be able to use the weights for the three damage categories, a series of models were developed, which are represented in a schematic way in Figure 8.

Damage Model for Emissions to Human Health

Four steps are needed for the calculation of the damages caused by emissions:

Fate Analysis. It models the transfer of chemical substances between the compartments and the degradation of substances, calculating the concentrations in air, water, soil and food.

Exposure. Based on the calculated concentrations it can be determined how much a substance is taken in by people or other life forms.

Effect Analysis. As the substance's exposure is known, it is possible to predict the types and frequencies of diseases or other effects.

Damage Analysis. The predicted diseases can now be expressed in a damage unit.

2.2.7 Damage Model for Ecosystems

Because mankind uses large portions of land for urban and agricultural purposes, many species are threatened with extinction. The disappearance of species is taken as the damage unit.

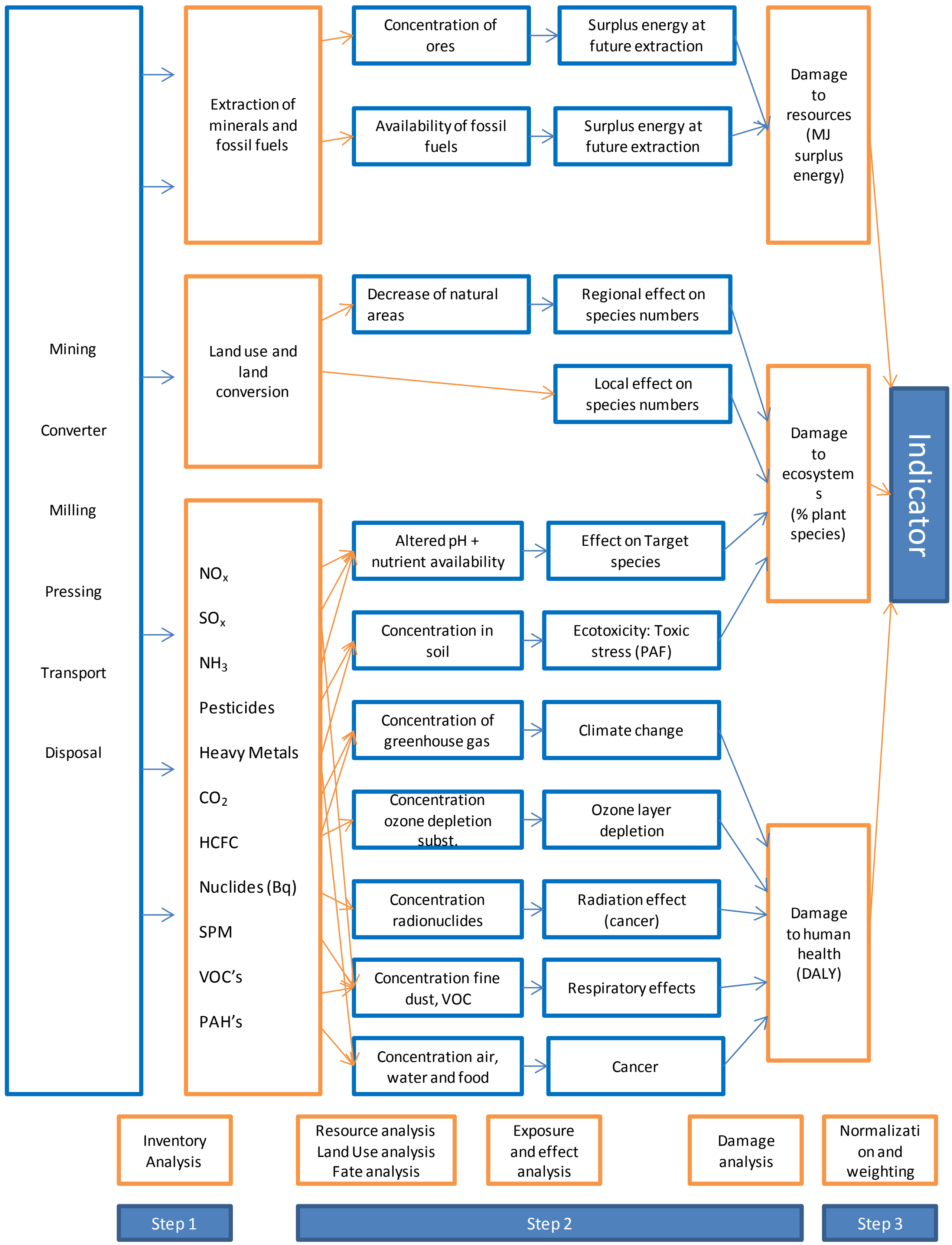

Figure 8 Damage Model (Housing, 2000)

2.2.8 Damage Model for resources

With the extraction of minerals, the quality is reduced for the remaining resources. The damage to resources is going to be reflected when future generations will use more effort to extract resources.

Inventory of the Process

The standard Eco-indicators are based on the energy database developed by ESU-ETH (Housing, 2000). In the data inventory is important to use a consistent methodology for:

- System boundaries.
- Allocation.
- Regional aspects.
- General data quality issues.

Uncertainties

There are two types of uncertainties when calculating the indicators.

1. Uncertainties about the correctness of the models used. Includes the choice of the time horizon in the damage model.
2. Data uncertainties. Refer to difficulties in measuring or predicting effects.

2.3 TRACI - Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts

The U.S. Environmental Protection Agency developed in 1995 the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) software, as an effort to provide an impact assessment tool for LCIA, pollution prevention, and sustainability metrics applicable for the United States.

The selection for the impact categories, which are generally divided on two types: depletion and pollution category, were considered because of the various programs within the U.S. Traditional pollution categories like ozone depletion, global warming, human toxicology, eco-toxicology, smog formation, acidification, and eutrophication are included in TRACI. The resource depletion categories are recognized as being of significance in the United States, especially for fossil fuel, land, and water use (Bare J. , Norris, Pennington, & McKone, 2003).

The following categories were selected for TRACI:

- Ozone depletion
- Global warming
- Smog formation
- Acidification
- Eutrophication
- Human health cancer
- Human health non-cancer
- Human health criteria pollutants
- Eco-toxicity
- Fossil fuel depletion
- Land use
- Water use

Many of the impact assessment methodologies within TRACI are based on "midpoint" characterization approaches (Bare et al, 2000). The impact assessment models reflect the relative potency of the stressors at a common midpoint within the cause effect chain (Bare J. , Norris, Pennington, & McKone, 2003). A midpoint analysis reduces the amount of forecasting, minimizing the complexity of the model and simplifying communication. The indicators and associated level of specificity in the simple cause-effect chains are as shown in Table 3. This method was used by Mary Ann for Life cycle assessment principles and practices (Curran, 2006), to normalized a U.S. database (Bare, Gloria, & Norris, 2006).

2.3.1 Impact Assessment Categories

Stratospheric Ozone Depletion

The stratosphere is located about 6 to 31 miles above the earth, contains a layer of ozone gas that protects living organisms from harmful ultraviolet-B radiation (UV-B) from the sun. UV-B has been linked to many harmful effects including various types of cancer, cataracts; to ecosystem damage such harm to crops, certain materials, and some forms of marine life.

Gases containing chlorine and bromine accumulate in the lower atmosphere that eventually transported to the stratosphere are converted into more reactive gases that destroy ozone. Several substances have been linked such chlorofluorocarbons (CFCs), halons, carbon tetrachloride, methyl bromide, and methyl chloroform.

Stratospheric ozone depletion refers to the reduction of the protective ozone within the stratosphere caused by emissions of ozone-depleting substances, increasing ultraviolet-B radiation reaching the earth. The potential contribution can be calculated as follows:

Ozone Depletion Index = $\sum_i e_i \times ODP_i$

Where e_i is the emission in kilograms of substance *i* and ODP_i is the ozone depletion potential for substance *i.*

Global Warming

Global warming is the potential change in earth's climate caused by the buildup of chemicals, such as greenhouse gases, that trap the heat from the reflected sunlight that would otherwise been liberated from the atmosphere. Earth's mean surface temperature has increased by about 0.8 °C, with about two-thirds of the increase occurring since 1980 (Choices & Council, 2011). Studies indicate that during the 21st century the global surface temperature is likely to rise a further 1.1 to 2.9 °C for their lowest emissions forecast (IPCC, 2007).

The effects that are related to the increase on the earth's temperature are sea level rise, widespread melting of snow and ice (enlargement and increase numbers of glacial lakes), increased heat content of the oceans, increased humidity, and the earlier timing of spring events such as leaf-unfolding, bird migration and egg-laying, among other effects.

Carbon dioxide is the most important anthropogenic Greenhouse Gas (GHGs). Its annual emissions have grown between 1970 and 2004 by about 80%, from 21 to 38 gigatonnes (Gt), and represented 77% of total anthopogenic GHG emissions in 2004 (IPCC, 2007). GHG, aerosols, land cover and solar radiation alter the energy balance of the climate system and are drivers of climate change.

TRACI uses global warming potentials for the calculation of the potency of the greenhouse gas emissions. A 100-year time horizons recommended by the International Panel on Climate Change is used by the U.S. for policy making and reporting (Bare J. , Norris, Pennington, & McKone, 2003).

Global Warming Index = $\sum_i e_i \times GWP_i$

Where e_i is the emissions in kilograms of substance *i* and GWP is the global warming potential for substance *i*.

Acidification

Acidification is the process that increases the acidity of water and soil systems caused by the uptake of anthropogenic carbon dioxide from the atmosphere. 30 to 40% of the carbon dioxide released by humans into the atmosphere dissolves into the oceans, rivers and lakes (Millero, 1995). Between 1751 and 1994 surface ocean pH is estimated to have decreased approximately 8.25 to 8.14 representing an increase of almost 30% in acidification (Jacobson, 2005). Another 20% of the carbon dioxide is absorbed by terrestrial biosphere.

The increasing acidification is linked to direct effects such as depressing metabolic rates in jumbo squid and depressing the immune responses of blue mussels, marine calcifying organisms to form biogenic calcium carbonate.

The TRACI model for acidification use the results of an empirically calibrated atmospheric chemistry and transport to estimate total terrestrial deposition of expected H^+ equivalents due to atmospheric emissions NO_x and NO_2 (Bare J. , Norris, Pennington, & McKone, 2003).

Eutrophication

Eutrophication is the fertilization of surface waters by nutrients that were previously limited. The limiting nutrient issue is key to a characterization analysis of phosphorus (P) and nitrogen (N). Eutrophication generally promotes excessive plant growth, such algae and plankton, causing the reduction in water quality; it was recognized as water pollution in the mid-20th century, where surveys have shown that 54% of lakes in Asia, 53% in Europe, 48 % in North America, 41% in South America, and 28% in Africa are eutrophic.

Terrestrial ecosystems are subject to similarly adverse impacts from eutrophication. High concentrations of nitrates in soil are undesirable for plants, endangering for example the majority of orchids species in Europe.

The TRACI characterization factors for eutrophication are the product of a nutrient factor and a transport factor (Bare J. , Norris, Pennington, & McKone, 2003). The nutrient factor models the strength of algae growth in the aquatic ecosystems of 1 kg of N versus 1 kg of P when each is the limiting nutrient.

Photochemical Smog

Is a unique type of air pollution which is caused by reactions between sunlight and pollutants like hydrocarbons and nitrogen dioxide. It is caused by small particles of material which become concentrated in the air; commonly caused by inversion, where cool air presses down on a column of warm air, forcing the air to remain stationary.

Photochemical smog is often invisible and it can be extremely harmful to human health, leading to irritations of the respiratory tract, causing emphysema, bronchitis, and asthma. It can cause eye and nose irritation and it dries out the protective membranes of the nose and throat and interferes with the body's ability to fight infection.

The U.S. EPA has developed the Air Quality Index to help explain air pollution levels to the general public.

Ecotoxicity

Refers to the effects that toxic chemicals have on biological organisms, such as human and ecosystems. The ultimate goal is to predict the effects of pollution so that the most efficient and effective action to prevent or remediate any detrimental effect can be identified.

Common environmental toxins such polychlorinated biphenyls (PCBs), pesticides, asbestos, and heavy metals, can limit the growth of seed germination of different plant species, can modify the distribution of individuals in a population and other degenerative effects on human health.

The ecological toxicity potential has been developed as a quantitative measure that expresses the potential ecological harm of a unit quantity of chemical released into an evaluative environment.

Resource Depletion

Land use. There is a widespread controversy and research in how to analyze the land use. Among the techniques are economic appraisals, species area relationships, and land-conversion and land-occupation assessments (Bare J. , Norris, Pennington, & McKone, 2003). The locality of the land is important because of its effects on economic value, its linkage to climate, topography, and resident plant and animal species, making it a unique location.

TRACI uses the density of threatened and endangered species in a specific area as a proxy for environmental importance. This approach operates under the assumption that land that has a higher number of threatened or endangered species is inherently more valuable in so far as species might completely disappear in the U.S.

Fossil fuel. Many techniques that analyze fossil fuel and energy consumption tend to preferred renewable energy sources than nonrenewable energy sources. An existing technique from Eco-indicator 99 was adapted to TRACI, which takes into account the fact that continued extraction and production of fossil fuels tends to consume the most economically recoverable reserves first, so that continued extraction will be more intensive in the future (Bare J. , Norris, Pennington, & McKone, 2003). This becomes true, once economically recoverable reserves of conventional petroleum and natural gas are consumed, leading to the use of nonconventional sources.

Water use. Water has been tracked as mass or volume terms in life cycle inventories, without subsequent characterization analysis that would weight different usage flows to take into account important differences among source types and usage locations. Rather than trying to capture the addition of pollutants into the environment, the impact category on TRACI is structured to capture the significant use of water in areas of low availability.

Human Health

Ambient concentrations of particle matter are strongly associated with changes in background rates of chronic and acute respiratory symptoms, as well mortality rates. TRACI develops a three stage method of life cycle impact assessment of these emissions. The first stage uses a model for output of atmospheric transport models to estimate the expected change in exposure due to emissions. The second

stage relies on epidemiological studies to provide concentration response functions that are used to relate changes in exposure in mortality and morbidity effects. The third stage translates the different mortality rates and morbidity effects on a single summary measure of disability-adjusted life-years (DALY) (Bare J. , Norris, Pennington, & McKone, 2003).

Human Cancer and Noncancer Effects. Relative comparison s of a large number of chemicals in terms of the potential to cause toxicological impacts are more important trying to characterize absolute risk. Local and worker health impacts are controlled through site-specific initiatives; comparisons are performed in life cycle analysis in the context of long-term exposures at a macro scale.

Table 3 Cause-effect chain selection **(Bare J. , Norris, Pennington, & McKone, 2003)**.

Impact Category	Midpoint level selected	Level of site specificity selected	Possible endpoints
Ozone depletion	Potential to destroy ozone based on chemical's reactivity and lifetime	Global	Skin cancer, cataracts, material damage, immune system suppression, crop damage, other plant and animal effects.
Global warming	Potential global warming based on chemical's radiative forcing and lifetime	Global	Malaria, coastal area damage, agricultural effects, forest damage, plant and animal effects
Acidification	Potential to cause wet or dry acid deposition	U.S., east or west of the Mississippi River, U.S. census regions, states	Plant, animal and ecosystem effects, damage to buildings
Eutrophication	Potential to cause eutrophication	U.S., east or west of the Mississippi River, U.S. census regions, states	Plant, animal and ecosystem, effects, odors and recreational effects, human health impacts
Photochemical smog	Potential to cause photochemical smog	U.S., east or west of the Mississippi River, U.S. census regions, states	Human mortality, asthma effects, plant effects
Ecotoxicity	Potential of a chemical released into an evaluative environment to cause ecological harm	U.S., east or west of the Mississippi River, U.S. census regions, states	Plant, animal, and ecosystem

Human Health: criteria air pollutants	Exposure to elevated particulate matter less than 2.5 µm	U.S., east or west of the Mississippi River, U.S. census regions, states	Disability-adjusted life-years (DALYs), toxicological human health effects
Human health: cancer	Potential of a chemical released into an evaluative environment to cause human cancer effects	U.S.	Variety of specific human cancer effects
Human health: noncancer	potential of a chemical released into an evaluative environment to cause human noncancer effects	U.S.	Variety of specific human toxicological noncancer effects
Fossil fuel	Potential to lead to the reduction of the availability of low cost/energy fossil fuel supplies	Global	Fossil fuel shortages leading to use of other energy sources, which may lead to other environmental or economic effects
Land use	Proxy indicator expressing potential damage to threatened and endangered species	U.S., east or west of the Mississippi River, U.S. census regions, states	Effects on threatened and endangered species (as defined by proxy indicator)
Water use	Not characterized at this time		Water shortages leading to agricultural, human, plant, and animal effects.

2.4 IMPACT 2002+

Life Cycle Impact Assessment (LCIA) methods objective is to connect the life cycle inventory result to the corresponding environmental impacts. Two main methodologies are the baseline to conduct an LCIA:

1. Classical impact assessment methods restrict quantitative modeling to early stages in the cause-effect chain to minimize uncertainties and group them in midpoint categories.
2. Damage oriented methods model the cause-effect chain up to the endpoint (damage) with high uncertainty.

The IMPACT 2002+ methodology utilize both approaches' advantages by grouping 14 midpoint categories into a structured set of four damage categories shown in Figure 9. The scope is common to all impact categories: overall long term effects considered through the use of infinite time horizons (Jolliet, et al., 2006). This method has been used by to assess the impact of cement inventories (Josa, Aguado, Cardim, & Byars, 2007).

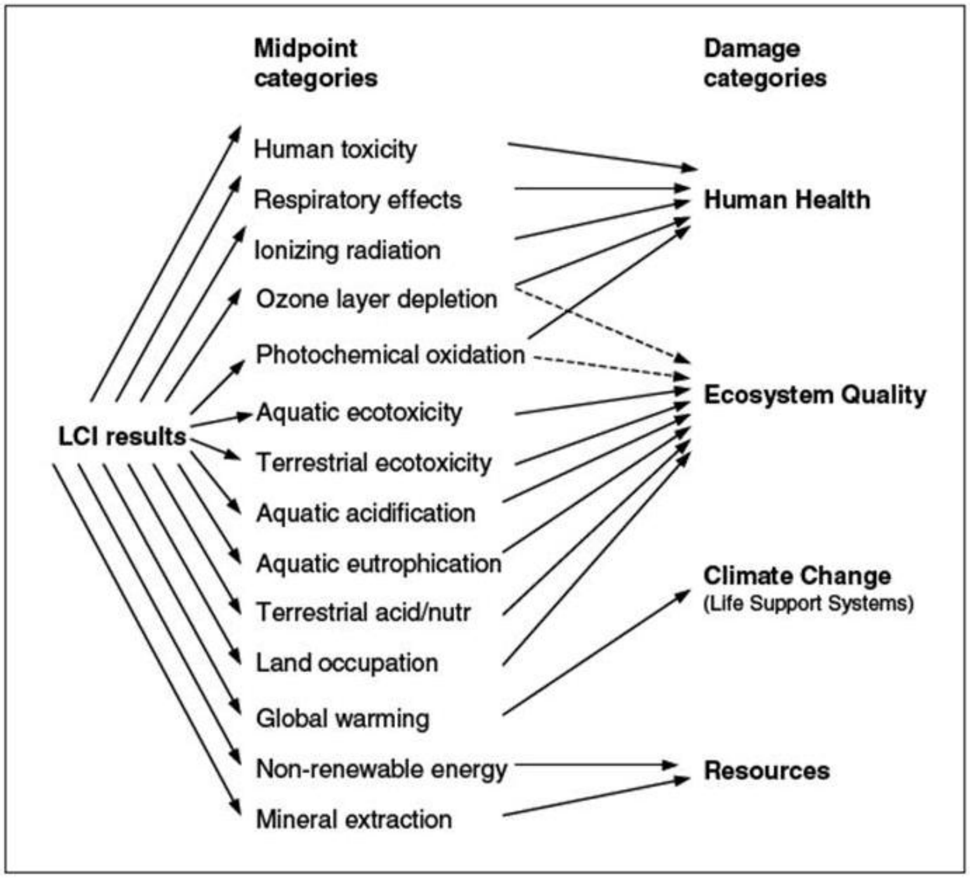

Figure 9 Scheme for IMPACT 2002+ (Jolliet, et al., 2006).

2.4.1 Midpoint Categories

Human Toxicity

The Human Toxicity Potentials (HTP) provides estimates of the cumulative toxicological risk and potential impacts associated with a specified mass of a chemical emitted to the environment. The Human Damage Factor is calculated as:

$HDF_i = iF_1 * EF_i - iF_1 * \beta_i * D_i$

Where iF is the fraction of mass of a chemical released into the environment, EF is the product of the dose-response slope factor, D the severity and β_i the risk of incidence.

Aquatic and Terrestrial Ecotoxicity

The impacts on aquatic ecosystems are treated slightly different to human toxicity, being the differences in the interest of the effects at species level and second the interface between fate and effect is at the concentration level. The Potentially Affected Fraction of species for fresh water ecosystems is estimated as follows:

$APFi = F_i^{mw} * \theta_i^{w} * \beta_i$

Where F_i^{mw} is the dimensionless fraction of the emission of substance *i*, is the equivalent residence time of substance *i* in water.

2.4.1 Damage Categories

The damage characterization factors of any substance can be obtained by multiplying the midpoint characterization potentials with the damage characterization factors of the reference on Table 4.

Human Health

Carcinogenic and non-carcinogenic effects, respiratory effects, radiation, ozone depletion all contribute to human health damages that can be expressed in Daily/$Kg_{emission}$ for the midpoint characterization factors (Jolliet, et al., 2006).

Ecosystem Quality

The ecosystem quality midpoint for terrestrial categories are based from Eco-indicator 99 and their impact can be directly determined as a Potentially Disappeared Fraction over a certain area in a period of time (Jolliet, et al., 2006).

Table 4 Characterization Factors (Jolliet, et al., 2006).

Midpoint categories	Damage factors	Units
Carcinogens	1.45E-06	DALY/Kg chloroethylene
Non-carcinogens	1.45E-06	DALY/Kg chloroethylene
Respiratory inorganics	7.00E-04	DALY/Kg PM2.5
Ozone layer	1.05E-03	DALY/Kg CFC-11
Radiation	2.10E-10	DALY/Bq carbon-14
Respiratory organics	2.13E-06	DALY/Kg ethylene
Aquatic ecotoxicity	8.86E-05	PDF*m^2*yr/kg*triethylene glycol
Terrestrial ecotoxicity	8.86E-05	PDF*m^2*yr/kg*triethylene glycol
Terrestrial acidification/nutr.	1.04	PDF*m^2*yr/kg SO_2
Land occupation	1.09	PDF*m^2*yr/m^2*organic arable land*yr
Global Warming	1	Kg CO_2/Kg CO_2
Mineral extraction	5.10E-02	mj/Kg iron
Non-renewable energy	45.6	MjJ/Kg crude oil

Normalization and Weighting

The idea of normalization is to analyze the respective share of each impact to the overall damage by applying normalization factors to midpoint or damage impact classes in order to facilitate interpretation (Jolliet, et al., 2006). The ratio of the impact of substances from a specific category for which characterization factors exist determines the normalization factor, which is the number of persons affected during one year per unit of emission. Table 5 provides the normalization factors for the four damage categories.

Table 5 Normalization factors for Damage categories. (Jolliet, et al., 2006)

Damage categories	Normalization factors	Unit
Human health	0.0077	DALY/pers/yr
Ecosystem Quality	4650	PDF*m^2*yr/pers/yr
Climate change	9950	Kg CO_2/pers/yr
Resources	152000	MJ/pers/yr

3. LCA for ChloraPrep© *Hi-Lite Orange*© 26 mL Applicator

CareFusion is a global corporation serving the healthcare industry with products and services that help hospitals measurably improve the safety and quality of care. The company develops market-leading technologies such as automated dispensing and patient identification systems, ventilators and respiratory products, skin prep products, surveillance services and surgical instruments.

CareFusion is a responsible company committed to environmentally sound practices in all areas of the business. The operations are managed in such way to minimize waste and reduce environmental impacts. The company is International Organization for Standardization (ISO) 14001:2004 Environmental Management Systems certified, being CareFusion - El Paso one of its certified locations.

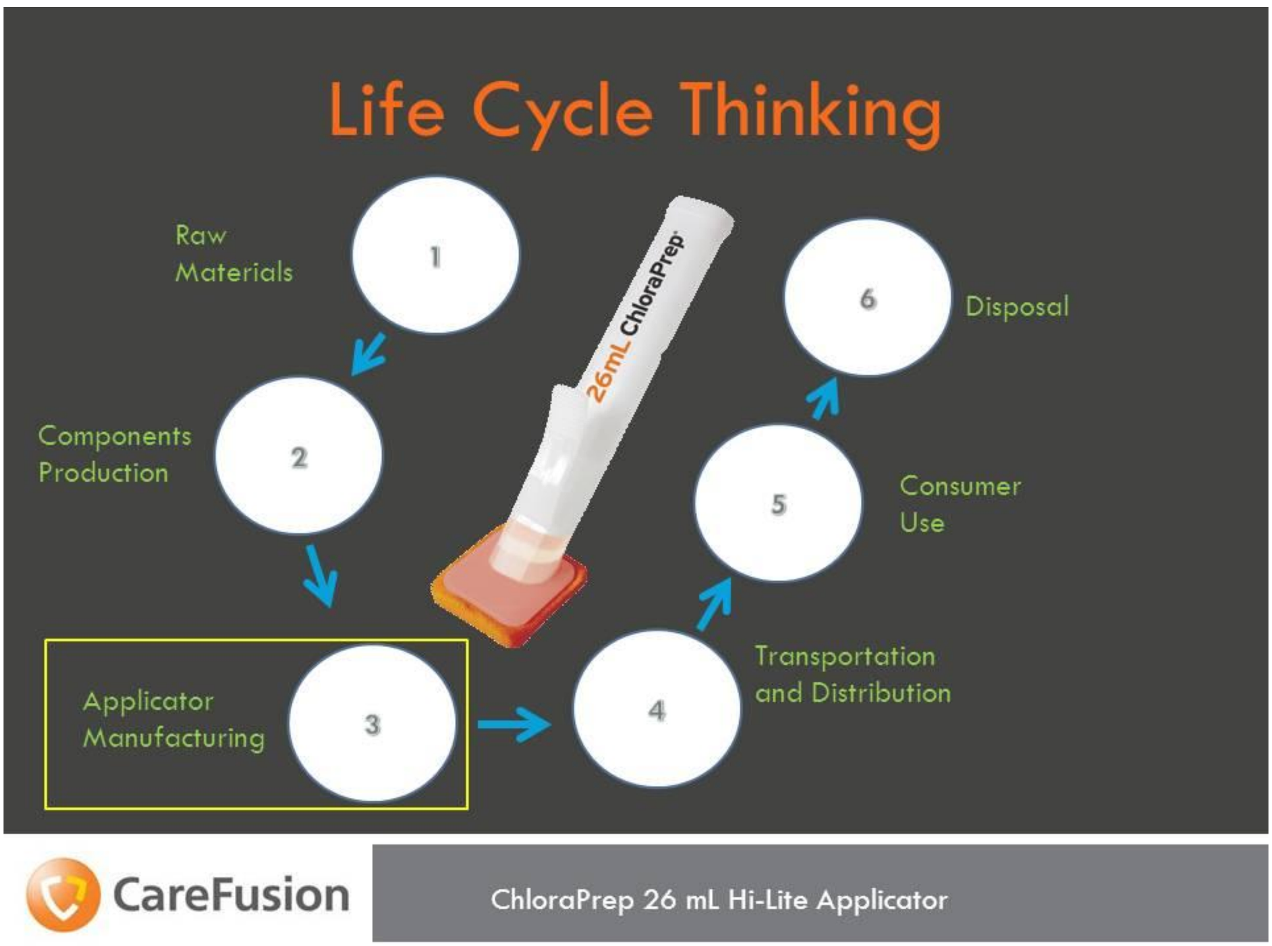

Figure 10 Applicator Life Cycle Schematic representation

3.1 PROJECT GOAL AND SCOPE

The goal of this Life Cycle Assessment is to provide to CareFusion, our intended audience, with an LCIA analysis for one of its products: ChloraPrep 26 mL Hi-Lite Applicator (260815). No LCA analysis has been ever performed for any of their products. Therefore, this opportunity will be the benchmark for the company to perform life cycle analysis, not only for their products, but for their processes as well.

The ChloraPrep 26 mL Hi-Lite Applicator is a product used in hospitals for the skin preparation prior to a surgery. Its formula is based on 2% chlorhexidine gluconate and 70% isopropyl alcohol that provide rapid-acting and persistent antiseptic activity against a broad spectrum of microorganisms.

The scope of the study comprises a "gate-to-gate", the Manufacturing processes, starting with the glass cutting and ending with the packaging of the product. Equipment and energy use are also considered in the analysis. Figure indicates the system boundaries that are considered in the study.

Table 6 Component origin

In-house	Outsourced
Solution	Body Endcap Foam Pledget Glass

The applicator consists of the following components: body, end cap, foam, pledget and vials. Some components are made by the company while others are purchased from different suppliers. A list of in-home products and outsourced products is provided in Table 6. It is important to mention that the component "Pledget" was part of the in-home product, but they relocated this operation to an outsource company since it contributed the most with emissions to air reaching and over passing the limits imposed by the Texas Commission on Environmental Quality policy. Therefore an LCA for their products while benefit the Company by identifying which processes contributes with high emissions, in order to improve them.

The unit function for the study is one ChloraPrep 26 mL Hi-Lite Applicator where the system function is to apply a preoperative skin antiseptic for the reduction of microorganisms on the skin. The product is a one-time use only.

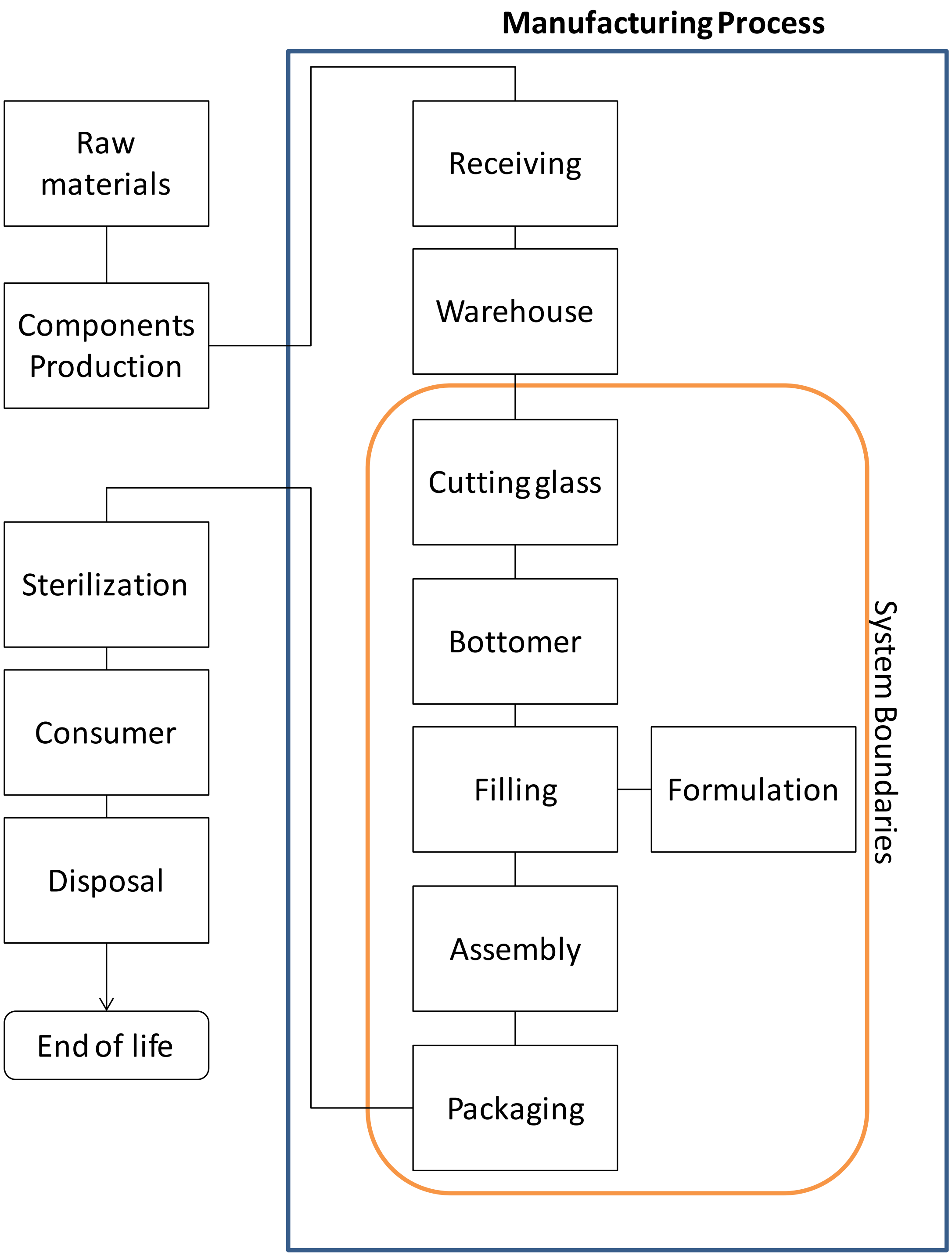

Figure 11 System Boundaries.

3.2 LIFE CYCLE INVENTORY

In order to perform an LCA, a qualitative catalog of the relevant inputs from the product is provided. The system boundary is delimited to the Manufacturing process. The following information for the inputs (components and energy) is given by process. The information provided is similar to the real inputs in order to protect the confidentiality of the company's private information.

The main assumption for the Life cycle inventory is that the same machines are always used in each process. The amount of energy and material stated at each process per component is based on the cycle time to process one single applicator. For energy inputs the amount that is being used is based on the Standard Operating Procedures for which each process has to operate. All the information was gathered from the Standard Operating Procedures and from the machine's manuals.

Table 7 Manufacturing Inputs by process

Cutting Glass	
Inputs	**Qty**
Glass	0.001 Kg
Electricity	0.000821 kWh
Propane Gas	0.0039 MJ
Oxygen	0.027 MJ

Formulation	
Inputs	**Qty**
Chlorhexidine Gluconate (2%)	.26 mL
Isopropyl Alcohol (70%)	9.1 mL
Water	3.64 mL

Bottomer	
Inputs	**Qty**
Propane Gas	0.0089 MJ
Electricity	0.0113 kWh
Oxygen	0.063 MJ

Filler	
Inputs	**Qty**
Electricity	0.0128 kWh
Propane Gas	0.0179 MJ
Oxygen	0.0738 MJ

Assembly	
Inputs	**Qty**
Electricity	0.0024 kWh
Body	0.026 Kg
Pledget	0.002 Kg
End cap	0.002 Kg
Foam	0.002 Kg

Packaging	
Inputs	**Qty**
Electricity	0.0376 kWh
Carton	.315 Kg
Plastic	.008 kg

3.3 LCA RESULTS

3.3.1 SimaPro 7

SimaPro7 is software that provides life cycle assessment (LCA) analysis. It allows complex life cycles to be modeled and analyzed in a systematic and transparent way. It has a number of applications, such as, product design, development of key performance indicators, calculation of carbon footprints, determination of environmental impact of products or services, environmental product declarations and environmental reporting (Consultants, 2008).

For this research SimaPro is being used to analyze the life cycle of one ChloraPrep 26 mL Hi-Lite Applicator within the manufacturing processes. It is also used in order to compare the software's results from Eco-indicator 99 and Impact 2002+ against the manual computation for Eco-indicator 95 and 99 and TRACI.

General LCAresults

Figure 12 represents the manufacturing process for one applicator in SimaPro 7.

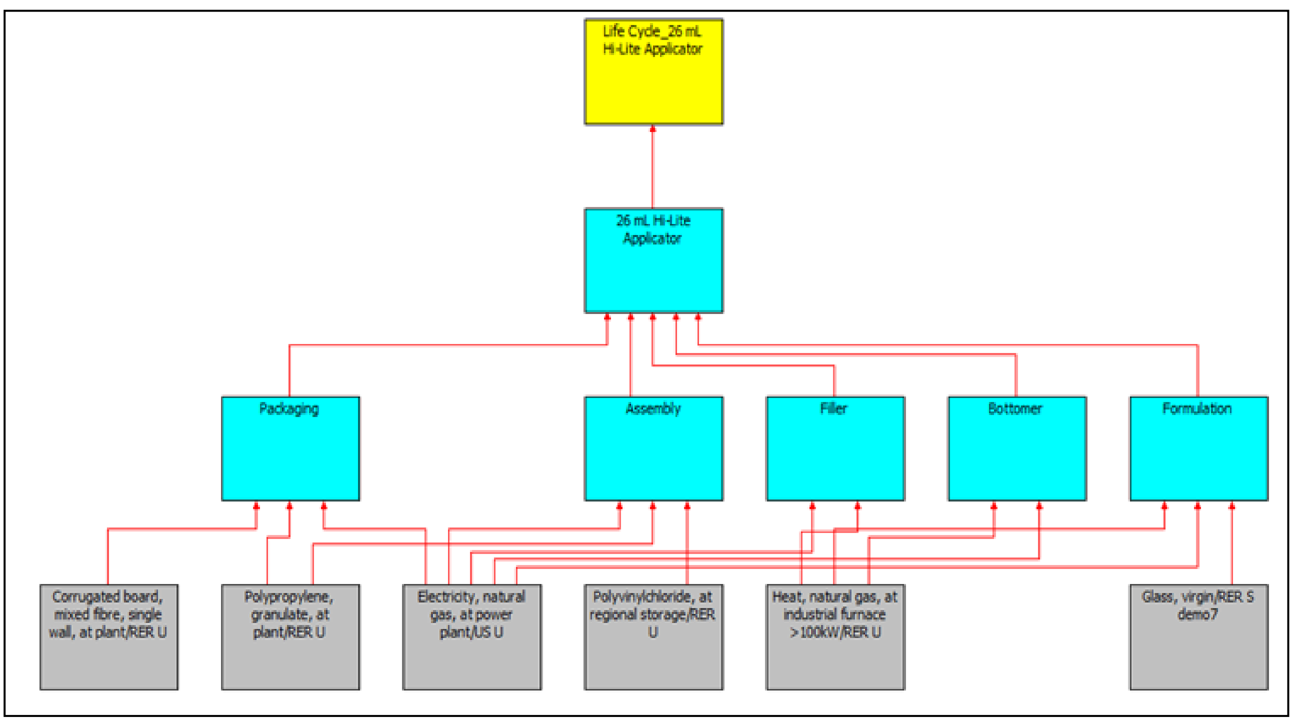

Figure 12 LCA Process flow

The following table provides the results given by the software. Based on the items of SimaPro's database, the main assumption when establishing the processes is that they are similar to components material and energy generation is generated by natural gas. From the analysis, the packaging phase has the higher emissions compared to all other processes. Formulation phase is not included since it could not be analyzed because there was no database available for the chemicals used in the product. An important assumption with these results is that electricity and natural gas are similar in origin to the ones available within the SimaPro 7database.

Table 8 SimaPro Results

	SimaPro item from database	**Qty**	**Result (pt)**
Cutting			
Glass	Glass, virgin/RER S demo 7	0.000821 kWh	0.0002
Natural gas	Heat, natural gas, at industrial furnace	0.0039 MJ	0.0001
Bottomer			
Electricity	Electricity, natural gas, at power plant/US	0.0113 kWh	0.0004
Natural gas	Heat, natural gas, at industrial furnace	.0089 MJ	0.0004
Filler			
Electricity	Electricity, natural gas, at power plant/US	0.0128 kWh	0.0008
Natural gas	Heat, natural gas, at industrial furnace	0.0179 MJ	0.0001
Assembly			
Body/End cap	Polypropylene, granulate, at plant/RER U	0.028 Kg	0.0084
Foam/ Pledget	Polyvinylchloride, at regional storage/RER U	0.004 Kg	0.0008
Electricity	Electricity, natural gas, at power plant/US	0.0024 kWh	0.0002
Packaging			
Carton	Corrugated boad/mixed fibre, single wall	0.0315 Kg	0.024
Plastic	Polypropylene, granulate, at plant/RER U	0.008 Kg	0.0364
Electricity	Electricity, natural gas, at power plant/US	0.0376 kWh	0.0389

Eco-indicator 99

The following figure provides the single score analyzing the product with the Eco-indicator 99. It is the same amount of points given by the general results, with the difference, that it categorizes the impact (Figure 13) and the damage (Figure 14).

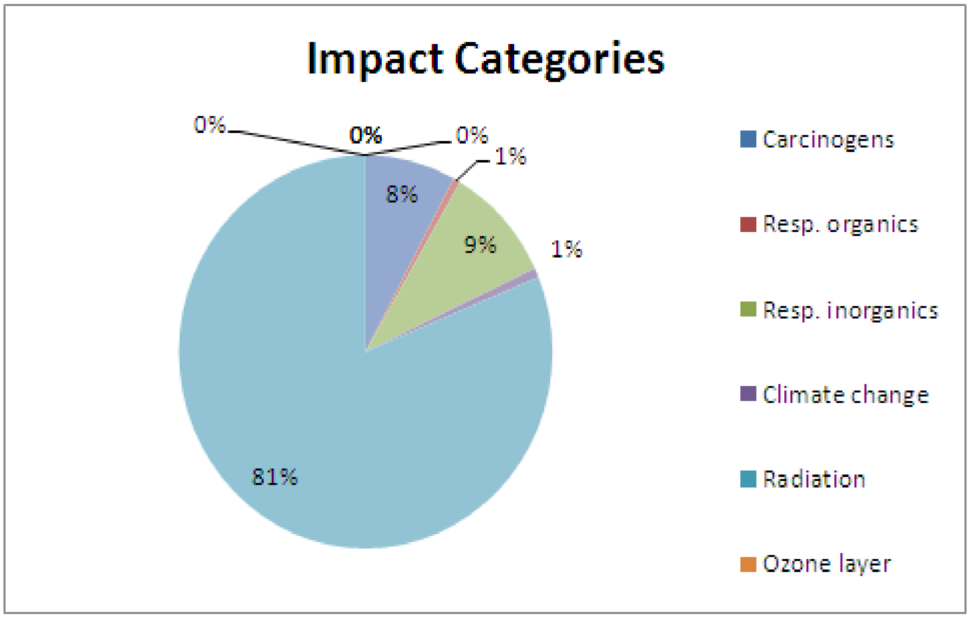

Figure 13 SimaPro Eco-indicator 99 Characterization

Table 9 SimaPro Eco-indicator 99 Numerical result - Charaterization

Impact Category	Unit	Total
Carcinogens	DALY	5.29E-08
Resp. organics	DALY	4.60E-10
Resp. inorganics	DALY	2.17E-07
Climate change	DALY	8.80E-08
Radiation	DALY	1.03E-09
Ozone layer	DALY	2.90E-11
Ecotoxicity	PAF*M2YR	9.02E-02
Acidification/ Eutrophication	PDF*M2YR	7.12E-03
Land use	PDF*M2YR	1.10E-01
Minerals	MJ Surplus	8.87E-03
Fossil fuels	MJ Surplus	9.34E-01

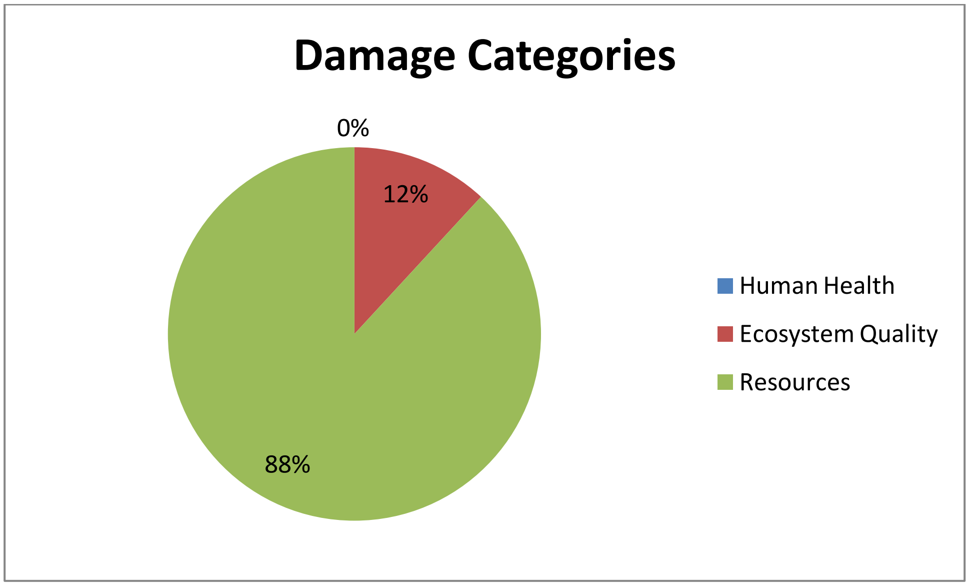

Figure 14 SimaPro Eco-indicator 99 Damage Assessment

Table 10 SimaPro Eco-indicator 99 Numerical result - Damage

Impact Category	Unit	Total
Human Health	DALY	3.60E-07
Ecosystem Quality	PDF*m2yr	1.27E-01
Resources	MJ Surplus	9.43E-01

IMPACT 2002+

The following figure provides the single score for the product analyzed with Impact 2002+ impact assessment method. The amount of points given by the general results is different compared to Eco-indicator 99, it gives its own type of result given on Impact 2002 Points (Pt). In addition, the categorization of the impact (Figure 13) and the damage (Figure 14) are shown respectively.

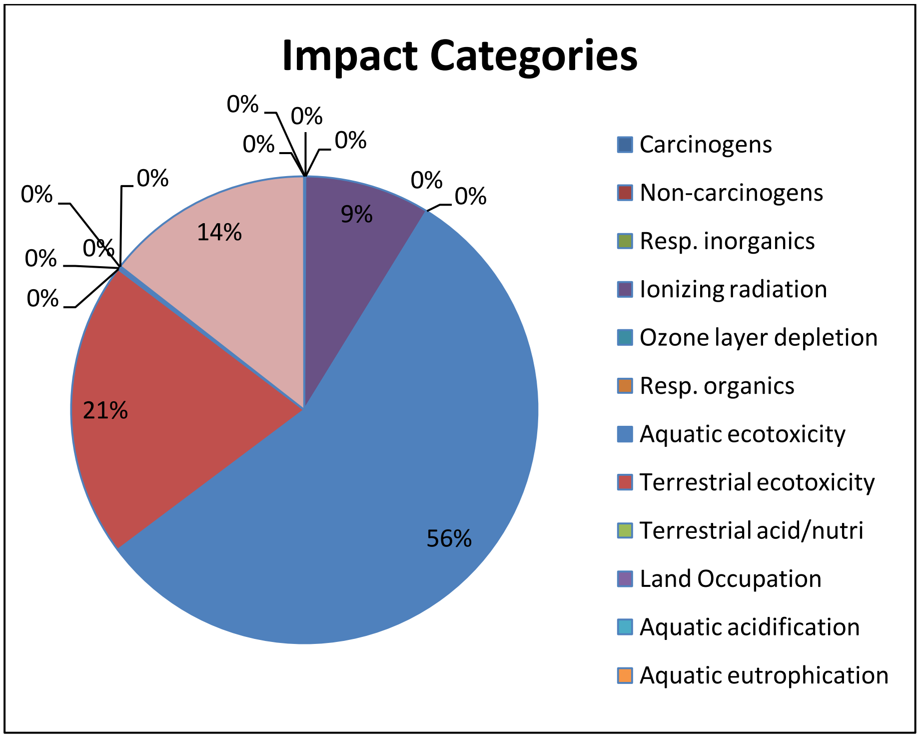

Figure 15 SimaPro Impact 2002+ Characterization

Table 11 SimaPro Impact 2002+ Numerical results- Characterization

Impact Category	Unit	Total
Carcinogens	Kg C2H3CL eq	3.27E-02
Non-carcinogens	Kg C2H3CL eq	8.85E-03
Resp. inorganics	Kg PM2.5 eq	2.91E-04
Ionizing radiation	Bq C-14 eq	5.14
Ozone layer depletion	Kg CFC-11 eq	3.08E-08
Resp. organics	Kg C2H4 eq	2.06E-04
Aquatic ecotoxicity	Kg TEG water	3.30E+01
Terrestrial ecotoxicity	Kg TEG soil	1.21E+01
Terrestrial acid/nutri	Kg SO2 eq	6.83E-03
Land Occupation	m2org.arable	9.82E-02
Aquatic acidification	Kg SO2 eq	1.71E-03
Aquatic eutrophication	Kg PO4 P-lim	9.50E-05
Global warming	kg CO2 eq	0.0402
Non-renewable energy	MJ Primary	8.52
Mineral extraction	MJ surplus	4.88E-03

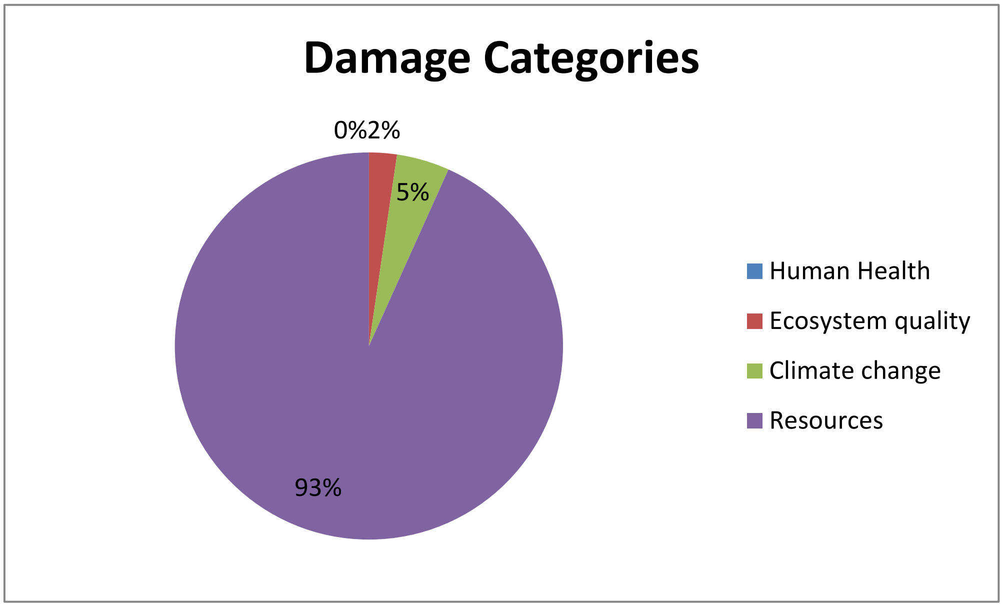

Figure 16 SimaPro Impact 2002+ Damage

Table 12 SimaPro Impact 2002+ Numerical results- Damage

Impact Category	Unit	Total
Human Health	DALY	3.20E-07
Ecosystem quality	PDF*m2*yr	2.12E-01
Climate change	Kg CO2 eq	4.02E-01
Resources	MJ primary	8.52

3.3.2 Eco-Indicator 95

Based on Figure the result for the analysis will give us a final score or Eco-indicator. By no means, this number necessarily represents an environmental emission. The Eco-indicator is based on the emissions that contribute to the effects, such as acidification and smog. Therefore, an Eco-indicator is a previously normalized and weighted score to be used within companies, for decision-making support tool when there is little time to carry out detailed analysis.

The Eco-indicator is intended to take generic decisions on materials, working principles and life cycles. The indicators are not intended for use in controlling the purchase of materials or in taking important investment decisions (PRe Consultants, 1996).

The following table represents the processes, the Eco-indicator value and the result of multiplying them for a final score.

Table 13 LCA for Applicator using Eco-Indicator 95

Cutting Glass			Eco-Indicator 95	
Inputs	**Qty**	**units**	**Indicator**	**result (mPt)**
Glass	0.001	Kg	2.1	0.0021
Electricity	0.000821	kWh	0.57	0.00046797
Propane Gas	0.0039	MJ	0.063	0.0002457
Oxygen	0.027	MJ		
			Total	0.00281367

Bottomer			Eco-Indicator 95	
Inputs	**Qty**	**units**	**Indicator**	**result (mPt)**
Glass	0.006	Kg	2.1	0.0126
Propane Gas	0.0089	MJ	0.063	0.0005607
Electricity	0.01133	kWh	0.57	0.005073
Oxygen	0.063	MJ		
			Total	0.0182337

Filler			Eco-Indicator 95	
Inputs	**Qty**	**units**	**Indicator**	**result (mPt)**
Electricity	0.0128	kWh	0.57	0.007296
Propane Gas	0.0179	MJ	0.063	0.0011277
Oxygen	0.0738	MJ		
			Total	0.0084237

Assembly			Eco-Indicator 95	
Inputs	**Qty**	**units**	**Indicator**	**result (mPt)**
Electricity	0.00241	kWh	0.57	0.0013737
Body	0.026	Kg	0.53	0.01378
Pledget	0.002	Kg	5.9	0.0118
End cap	0.002	Kg	0.53	0.00106
Foam	0.002	Kg	5.9	0.0118
			Total	0.0398137

Packaging			Eco-Indicator 95	
Inputs	**Qty**	**units**	**Indicator**	**Result (mPt)**
Electricity	0.0376	kWh	0.57	0.021432
Carton	0.315	Kg	1.4	0.441
Plastic	0.008	Kg	0.16	0.00128
			Total	0.463712

Each process has a Total Eco-indicator score where the results reveal that Packaging phase has the greatest impact. The number of points is many times higher than combining the other process scores. It is important to note that formulation phase is not considered within this analysis, since no Eco-points where available for chemicals at this time. However, it can be assumed that Formulation and Packaging phases are the processes with most impact.

3.3.3 Eco-indicator 99

The main difference between the Eco-indicator 95 and Eco-indicator 99 is how the methodology was conceived; Eco-indicator 95 was developed from a so called Distance-to-Target approach, while Eco-indicator 99 is based on the Damage approach. The Eco-indicator 95 and 99 values are not compatible. Below is the same product's flow process analyzed with Eco-indicator 99.

Table 14 LCA for Applicator using Eco-Indicator 99

Cutting Glass			Eco-Indicator 99	
Inputs	**Qty**	**units**	**Indicator**	**result**
Glass	0.001	Kg	2.1	0.0021
Electricity	0.000821	kWh	37	0.030377
Propane Gas	0.0039	MJ	5.4	0.02106
Oxygen	0.027	MJ		
			Total	0.053537

Bottomer			Eco-Indicator 99	
Inputs	**Qty**	**units**	**Indicator**	**result**
Glass	0.006	Kg	2.1	0.0126
Propane Gas	0.0089	MJ	5.4	0.04806
Electricity	0.01133	kWh	37	0.41921
Oxygen	0.063	MJ		
			Total	0.47987

Filler			Eco-Indicator 99	
Inputs	**Qty**	**units**	**Indicator**	**result**
Electricity	0.0128	kWh	37	0.4736
Propane Gas	0.0179	MJ	5.4	0.09666
Oxygen	0.0738	MJ		
			Total	0.57026

Assembly			Eco-Indicator 99	
Inputs	**Qty**	**units**	**Indicator**	**result**
Electricity	0.00241	kWh	37	0.08917
Body	0.026	Kg	21	0.546
Pledget	0.002	Kg	480	0.96
End cap	0.002	Kg	21	0.042
Foam	0.002	Kg	480	0.96
			Total	2.59717

Packaging			Eco-Indicator 99	
Inputs	**Qty**	**units**	**Indicator**	**result**
Electricity	0.0376	kWh	37	1.3912
Carton	0.315	Kg	69	21.735
Plastic	0.008	Kg	9.1	0.0728
			Total	23.199

The results on the form reveal that Packaging phase has the greatest impact. The result is similar overall as the one obtained with Eco-indicator 95, but it cannot be assumed that for other analysis will similarly occurred. The eco-indicators 99 have been changed and they are more detailed in where they should be used, which in Eco-indicator 95 all options are generic values.

3.3.4 TRACI

The applicator has a phase where the Solution is produced. Unfortunately, the Eco-indicators do not have scores or indicator for chemicals. Therefore, an analysis using TRACI is performed. The limitations about TRACI as its name states the analysis for only chemicals and not other type of materials or energy used within the process. However, this limitation do not decrease the valuable input for a life cycle analysis. The following table describes the components for the solution.

Table 15 Applicator's LCA - Formulation Phase

Formulation		
Inputs	**Qty**	**units**
Chlorhexidine Gluconate (2%)	0.52	mL
Isopropyl Alcohol (70%)	18.2	mL
Water	7.28	mL

The following Table 16 shows the normalization factors for each impact category for the Isopropyl Alcohol. Table 17 represents the total amount of emissions for Isopropyl Alcohol categorized based on the amount used to elaborate 26 mL of solution. The database, provided by Jane Bare, Researcher for the U.S. Environmental Protection Agency (Bare J. , 2011) (Bare J. , 2012), did not included the Substance Chlorhexidine Gluconate.

Table 16 TRACI Analysis for Applicator Normalization

Substance Name	Smog Air (kg O3 eq / kg substance)	Ecotox. CF [CTUeco/kg], Em.airU, freshwater	Ecotox. CF [CTUeco/kg], Em.airC, freshwater	Ecotox. CF [CTUeco/kg], Em.fr.waterC, freshwater	Ecotox. CF [CTUeco/kg], Em.sea waterC, freshwater	Ecotox. CF [CTUeco/kg], Em.nat.soilC, freshwater	Ecotox. CF [CTUeco/kg], Em.agr.soilC, freshwater
Isopropyl Alcohol	6.14E-01	8.05E-02	7.94E-02	2.46E+00	1.22E-03	5.63E-01	5.63E-01

Table 17 TRACI Analysis for Applicator Results

Substance Name	Smog Air (kg O3 eq / kg substance)	Ecotox. CF [CTUeco/kg], Em.airU, freshwater	Ecotox. CF [CTUeco/kg], Em.airC, freshwater	Ecotox. CF [CTUeco/kg], Em.fr.waterC, freshwater	Ecotox. CF [CTUeco/kg], Em.sea waterC, freshwater	Ecotox. CF [CTUeco/kg], Em.nat.soilC, freshwater	Ecotox. CF [CTUeco/kg], Em.agr.soilC, freshwater
Isopropyl Alcohol	0.0087862	0.0011517	0.001136	0.035239173	1.7466E-05	0.00805884	0.00805884

To give a clear example, let's compare the emissions of a single car. A car will emit about 22.7 kg of smog for every 100 000 miles. Therefore 0.008 kg of alcohol will have the same emissions as riding a car for 35.24 miles.

Overall Life Cycle Analysis

The analysis identify that Packaging phase has the higher impact within the Manufacturing process. A team should prioritize in modifying how the product is packaged. It is clearly stated that carton has the higher impact on the score and the amount of electricity is a clear second priority to improve the process.

Since the Eco-indicator 95 and 99 is limited and do not contain eco-indicator for chemicals, the implementation of TRACI is an excellent resource to approximate the impacts of the chemicals used in the product. Is common to see that different methodologies are used within the same analysis in order to calculate and identify the sources of a product's environmental impact.

The comparison between the amounts of emissions produced by a car with the amount of the alcohol from the product, gives an understandable picture on the magnitude of the emissions for one single applicator. There is no need to calculate an Eco-indicator score to be aware that the formulation phase it should be also addressed in order to be improved.

3.4 COMPARISON

The following table summarizes the results of all four Impact Assessment methodologies.

Method	Results
Eco-indicator 95	Packaging Phase with highest Eco-value Carton, major contributor
Eco-indicator 99	Packaging Phase with highest Eco-value Carton, major contributor
IMPACT 2002+	Packaging Phase with highest value Electricity and Plastic, major contributors
TRACI	Isopropyl Alcohol

Eco-indicator 95, Eco-indicator 99, and IMPACT 2002+ coincide that Packaging phase should be considered to be analyzed more closely, since it has the highest value compared to other processes. Although the IMPACT 2002+ considered that plastic and energy consumption are the major contributors, while Eco-indicator 95 and 99 concludes that carton is the major contributor, the life cycle inventory for this process could be entirely analyzed to look for different feasible options to improve the process. Changing one of the materials may be considered difficult because of certain limitation, but there is still an opportunity to improve the process by reducing the energy consumption or other ways the researcher may considered.

Considering the methodologies by themselves we can conclude that Eco-indicator 95 is a tool that can be used to perform life cycle impact assessment analysis. Its broad scope to perform analysis for different life cycle phases makes it suitable for researchers to encompass more relevant data in the life cycle inventory. However, the database available for the Eco-indicator values for defined processes and

materials are general in description, where assumptions should be made as in processes or materials in the database are similar to the life cycle inventory. Moreover, the researcher has to consider that this methodology utilizes that Midpoint approach, meaning the analysis will only consider the general effect of the emissions.

Eco-indicator 99 methodology is based on the Damage approach, where it classifies a system's flows into environmental themes modeled each in damage to human health, ecosystem health or damage to resources; suitable for a researcher if the analysis has an objective of which kind of damage wants to prevent or decrease. Its database is extended from its previous version, where materials and processes are more detailed in their specifications, minimizing the need to state assumptions in the analysis for the life cycle inventory. Similar to Eco-indicator 95, this method is suitable to perform a broad life cycle analysis.

IMPACT 2002+ has the same damage approach, where it considers the overall long term effects, using 14 impact categories (Midpoints) and four damage categories (endpoints). Similarly to the previous methodologies, this method can be used to model the entire life cycle of the system in question. However, there is no database available, where eco-indicators are provided for certain materials and processes. Eco-indicators can be calculated manually, but the complexity of the information needed it may not be adequate if there is a time constraint for the analysis. Software such GaBi and SimaPro considered this method within their options to perform the analysis.

TRACI is a limited impact assessment approach, similarly its method is based on the Midpoint but it focuses solely on chemicals and substances to assess the environmental impact. The U.S. EPA developed this tool to be accessible to the public however currently at this time there is no access to download the software. It is possible to contact EPA to gain access to its database used for chemicals and substances. This method it could be used to perform an analysis, if within the life cycle phase's chemicals are involved.

4. Conclusion

A Life Cycle Analysis is an important tool to make more informed decisions through a better understanding of the human health and environmental impacts of products, processes, and activities. Society has become concerned about the issues of natural resource depletion and environmental degradation.

Following the LCA basic process, goal definition and scoping, life cycle inventory, life cycle impact assessment, and life cycle interpretation, the researcher can develop a systematic evaluation of the environmental consequences associated with a given product. Analyze environmental trade-offs associated with one or more specific products/processes to help gain stakeholder acceptance for a planned action.

The Life Cycle Impact Assessment is the evaluation of potential human health and environmental impacts of the environmental resources and releases identified during the Life Cycle Inventory. It attempts to establish a link between the product and its environmental impacts. Throughout the time, several successful efforts have developed different methodologies being the most popular, and practically a base for many other methods, the Eco-Indicators 95 methodology. The Eco-indicator 95 and 99 are methodologies created and based with European data, specifically from the Dutch (Netherlands) population.

The U.S. Environmental Protection Agency in an attempt to create a methodology based on U.S. data developed the Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts. The Impact 2002+ methodology, developed by the University of Michigan, proposes an attractive implementation of a combined midpoint/damage approach, similarly as Eco-indicator 99. However, the database in which Impact 2002+ is the same as Eco-Indicator 99, meaning the data came from a European resource.

However, this methodologies do not considered the water consumption or utilization that can be involved directly or indirectly. Water is a vital element for the planet and its inhabitants. The water is only assessed if the researcher considers it on its life cycle inventory as part of the inputs and outputs for the system. Water saving is one of the biggest challenges for our times as it is climate change reduction.

The softwares available will considered only the emissions to water from the life cycle inventory, but not the consumption of the water within the life cycle of the system.

All assumptions within the LCA have to be stated clearly in order to understand and validate the results. Unfortunately, one assumption is not clearly stated when using an Impact Assessment Methodology, which is the background on which the chosen methodology is based. If a researcher is conducting a project in America, specifically in the U.S. the results will be based on European data if and only if is not using the TRACI methodology. Moreover, the software available for LCA such as GaBi 5 or SimaPro, which are the most used to perform LCA's, come from Europe.

The results are never conclusive but they clearly state an approximation on how much emissions and their impacts. This clearly states the need to increase the efforts to develop a methodology with a database based strictly on U.S. data.

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Vita

Aaron A. Martinez was born in El Paso, Texas in 1986. He is son of Justino S. Martinez and Alicia Gallardo. He finished his high-school education in Preparatoria El Chamizal in Ciudad Juarez, Mexico, graduating in 2004. He attended The University of Texas at El Paso and received a Bachelor of Science in Industrial Engineering degree in 2010. During the summer of 2010 he had a research internship at Pacific Northwest National Laboratory collaborating for research in development and validation of models that describe the joint behavior of electric power markets and systems, as well research for the production or acquisition of explosive and chemical ingredients from domestic products. In Fall of 2010 he become an entrepreneur by starting its own business for the triathlon market. In January 2011, he started his studies towards a Master in Science in Industrial Engineering working for the Industrial, Manufacturing, and Systems Engineering Department under the supervision of Dr. Jose Espiritu-Nolasco in the areas of Quality and Sustainable Engineering. In fall 2012 he started working for CareFusion working as a Process Flow Organizer Intern, Production Supervisor for Third shift and finally as a Validation Engineer, all within the first six months.

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