University of Southern Queensland

Faculty of Engineering and Surveying

LIFE CYCLE ASSESSMENT OF ULTRA PURE WATER PLANT IN SEMICONDUCTOR INDUSTRY

A dissertation submitted by

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towards the degree of

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ABSTRACT

This project seeks to investigate the process of manufacturing ultra-pure water in a semiconductor company. Literature reviews related to water treatment and purification is carried out in order to achieve the aim of the project. Damages to human health, ecosystem quality and resources are shown in the LCA model. These results can be used as a guide for future improvement of the product or process. These improvements can also minimize the occupational health and safety risks in the process and cost in operation.

LCA model is an ideal tool to reduce environmental impact and helps to achieve sustainable development. It complies with international standards (ISO 14040-14049). It is a powerful and professional tool used worldwide to assess products, processes and services. LCA can also assist regulators to formulate environmental legislation.

The result show that RO plant consumes 30.6% electricity compares to UPW plant 69.3%, which is twice the amount of energy required to run the machines and technology which created ultra pure water from raw water. This has a serious impact on the environment especially the energy consume by these machines impacting the ecology, human health and resources. UPW plant in STMicroelectronics Pte Ltd characterization score per impact category is 70% whereas RO plant in Numonyx Pte Ltd characterization score per impact category is 30%. This is due to more processes involve in the production of UPW such as UV sterilizer, membrane degasifier, continuous de-ionizer, mixed bed, ultra filtration and pumps.

Therefore it is recommended not to have an RO plant build in STMicroelectronics Pte Ltd facilities as the effect can be more severe in terms of electricity cost and the return of investment is long term.

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Limitations of Use

Certification

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

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

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Signature

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Date

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Many thanks to STMicroelectronics Pte Ltd, Singapore, for providing necessary information and data. I would also like to thanks the staffs from UPW facility department, especially the manager Mr Sivakumar for the interview and support he has given. I deeply appreciate their help and friendship.

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ABBREVIATIONS

CDI	Continuous De-ionizer
CMP	Chemical Mechanical Planarization
DIW	De Ionized Water
DQI	Data Quality Input
FRP	Fibre Reinforced Plastic
HERO	High Efficiency Reverse Osmosis
ISO	International Organization of Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
PET	Poly ethylene terephthalate
PM	Preventive Maintenance
PP	Poly Propene
PVDF	Polyvinylidene Fluoride
RO	Reverse Osmosis
SETAC	Society of Environmental Toxicology and Chemistry
SIMAPRO	System for Integrated Environmental Assessment of Products
TDS	Total Dissolve Solid
TOC	Total Organic Carbon
UF	Ultra Filtration
UNEP	United Nations Environmental Programme
UPW	Ultra Pure Water
USEPA	United States Environmental Protection Agency
UV	Ultra Violet
VFD	Variable Frequency Drive
WWTP	Waste Water Treatment Plant

CHAPTER 1

INTRODUCTION

1.1 Introduction

Sustainable development has been a global and international issue related to human activities that causes pollution and degrading of the environment. Sustainable development is defined as a balance structure that aims to meet human needs while preserving the environment so that these needs can be met not only in the present but also for future generations. It can also be defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. (Mintzer, 1992)

One of the world natural resources is water and it is the most important substance we use in our every day life. Therefore we must use it efficiently and the semiconductor industry is one that can have a direct impact on the region's water supply. Ultra-pure water is purified water generated through series of chemical process engineering units designed to remove contaminants from the water. The production process involves pumping feed water, filtration, reverse osmosis, chemical treatment, vacuum degasification, ion exchange, ultraviolet sterilization and ultra filter membrane filtration. However, the required hardware for the application of these technologies has a severe impact to the environment in manufacturing and end of life.

In this project, LCA is an ideal tool to achieve sustainable development in a modern technology and society. Improvements can be made after understanding and identifying where the environmental impacts and damages come from. SIMAPRO will be used to analyze and quantify the environmental impacts caused by manufacturing a UPW plant in a semiconductor industry. This product is chosen because it is used a lot in a wafer manufacturing company and the cost of producing a litre of ultra pure water is very expensive. Therefore after obtaining the results, a solution to the process or materials used can be improved.

1.2 Objectives

The main objective of this project is to set up an LCA model in order to access environmental information on UPW plant. A literature review of LCA studies of water treatment will be introduced as a guideline for the research.

A detailed study of the LCA methodology and the software available in the market was assessed for pros and cons to produce good results. Furthermore after comprehending the LCA methodology, it is easier to define the goal and scope of a UPW plant in a wafer manufacturing company. The software chosen for the LCA study will make understanding easier as well as produce results for better quality process and reduce cost of production. This will be followed by the creation of a running model using data from previous studies, reference material and reliable data value available. The functional unit for this study is required to start the software analysis to be carried out. After the model flowchart is established, the real data can be input and show some relevant results. The results are compared with previous study to make sure the objective is achieved. In order to make sure the trends shown by the model is correct, a model sensitivity analyses is carried out to see any change if there is variation. After the model had been tested, the results will be evaluated and suggestions for improvement can be made to the UPW system.

Chapter 2

Literature Review

2.1 Introduction

LCA or life cycle assessment is a useful tool to examine a system performance starting from the extraction of raw materials from the earth followed by the operations until the final disposal of the material as waste. It enables a manufacturer to know how much energy and raw materials are used and how much solid, gases and liquid wastes are generated at each stage of the product life. LCA helps to analyze the process involved, improve the product quality by using environmental friendly products and allows consumer with more information on the choices of the product. LCA complies with the international standards ISO 14040 to 14049. LCA is also known as life cycle analysis, eco-balance and cradle to grave analysis.

2.2 History of LCA

In the early 1960's, there were concerns over sustainability of the raw material and energy supply which sparked interest in finding new resources of supplies and account for what the energy is being used for. Later in the 1960's, studies are performed to estimate costs and environmental implications of alternatives sources of energy.

The initial study is done on The Coca Cola Company in USA which is the foundation of the methodology of Life cycle inventory analysis. The aim is to compare which different container being produced has the lowest releases to the environment and least affected the supply of natural resources. At that time, the available data were taken from government documents or technical papers.

Between 1970 and 1975, the standard methodology practice for all companies and industries to quantify the resource used and environmental release were developed after concerns over oil shortages and interest from the public. Although the assumptions and techniques used were reviewed, the results were reasonable.

In the early 1980's, as interest grew with the influence of the oil crisis, the concerns were shifted to issues on hazardous and household waste management. However, life cycle inventory methodology was improved, focusing much on energy requirement. At the same time, the European also developed the same approach used in the USA.

When solid waste became a world wide issue in 1988, LCA again is used to solve the environmental problems. The methodology is further refined and improved with more bodies involved. (SETAC 1991; SETAC 1993; SETAC 1997)

In 1991, to avoid any contradicting results to promote manufacturer's product, this led to the development of the LCA standards in the ISO 14000 series (1997 through 2002).

In 2002, the United Nation Environment Programme (UNEP) joined forces with the Society of Environmental Toxicology and Chemistry (SETAC) to launch the life cycle initiative. The aim is to put life cycle thinking into practice and improve the supporting tools through better data and indicators.

2.3 International Organizations and Standards On LCA

There are 3 international bodies associated with the development and application of LCA. They are SETAC (Society of Toxicology and Chemistry), ISO (International Organization of Standardization) and UNEP (United Nation Environmental Programme) and each of them are discussed here.

2.3.1 SETAC (Society of Toxicology and Chemistry)

SETAC was founded in 1979 and grew its membership base on the communication among environmental scientists to discuss environmental issues in a forum. The strength of SETAC is its commitment to balance the interest of academia, business and government. SETAC is concerned about global environmental issues and the scope of science is much broader than any other organization. "LCA is one of the several techniques of environmental management". (SETAC guidelines for Life Cycle Assessment: A "code of practice", 1993).

2.3.2 ISO (International Organization of Standardization)

LCA is recognized as an environmental management tool which complies with the international standards (ISO 14040-14049) since 1990. The ISO 14000 family series include goal and scope definition and inventory assessment (ISO 14041, 1998), impact assessment (ISO 14042, 2000a), interpretation (ISO 14043, 2000b) and general introductory framework (14040, 1997). This project follows the ISO standards at all time since it is the best practice for conducting LCA.

2.3.3 UNEP (United Nation Environmental Programme)

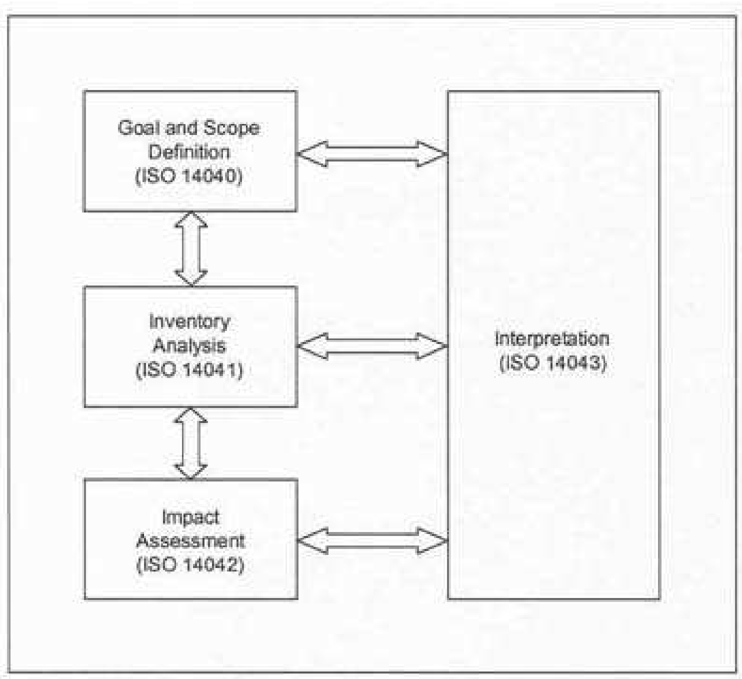
UNEP was founded as a result of the United Nations Conference on the Human Environment in June 1972 and its aim is to assist developing countries in implementing environmentally sound policies and practice sustainable development in their environmental activities. UNEP LCA publication started in 1996 entitled 'LCA:What it is and How to do it' followed by another publication in 1999 entitled 'Towards a Global Use of LCA'. The next publication by UNEP with support of USEPA (United States

Environmental Protection Agency) in 2003 entitled ‘Evaluation of Environmental Impacts in LCA’ aims to improve understanding of the impacts in LCA and encourage applications in industry and government decision making.

2.4 LCA Methodology

There are 4 separate phases, described in ISO 14040 when doing Life Cycle Assessment and they are shown in the figure below.

1. ISO 14041: Goal and Scope definition
2. ISO 14041: Inventory Analysis
3. ISO 14042: Impact Assessment
4. ISO 14043: Interpretation



(Source: agnet, 2001)

Figure 2.1: Life Cycle Methodology

2.4.1 Goal and Scope

The goal in a LCA study is to achieve an objective to a problem by applying the results to the intended audience. The scope of the study described the depth and show that the purpose can be met with the actual extent of the limitations. The functional unit is a key element of the LCA which has to be clearly defined as it is a reference to which the inputs and outputs are related. The system boundaries determine which unit processes are to be included in the LCA study which is set initially during the scope phase. Reliability of the LCA studies depends on the extent to which data quality requirements are met.

2.4.2 Life Cycle Inventory

LCI develops a system model containing the amounts of inputs and outputs throughout the life cycle of the product, process and activity. The inputs refer to raw materials and energy whereas the outputs are products and solid, liquid and gaseous emissions. All relevant data are collected and compiled and the data evaluated are used to compare environmental impacts and potential improvements. The data collected must be related to the functional unit defined in the goal and scope definition. The LCA inventories and modeled using dedicated software packages.

2.4.3 Life Cycle Impact Assessment

Life cycle impact assessment aims to evaluate the contribution to impact category such as global warming, acidification etc. Characterization is the first step calculated base on the LCI results which shows the environmental profile of the product system.
The next steps are normalization and weighing but theses are both voluntary according the ISO standard. Normalization provides a basis for comparing different types of environmental impact categories. Weighing implies assigning a weighting factor to each impact category depending on the relative importance.

2.4.4 Life Cycle Interpretation

The Interpretation phase aims to evaluate the results from either Inventory Analysis or Impact Assessment and to compare them with the goal defined in the first phase. (Jacqeline Aloisi de Larderel, 2003). The first step is to identify the important results of the Inventory Analysis and Impact Assessment. The next step is to evaluate the results with consistency in the following routines: completeness check, sensitivity check, uncertainty analysis and consistency check. The last step is conclusion, recommendation and reporting of the final outcome.

2.5 LCA Data Demand

LCA requires a large amount of data since there are several processes involved in a life cycle of a typical product. These processes need to be identified in details because each process specification involves a lot of items such as consumption of electricity, amount of materials used and produced, emissions to atmosphere and generation of waste.

The databases developed should contain data on general processes such as the generation of electricity, the different mode of transport and production of raw materials (Nico van den Berg, 1996)

2.6 Limitations of LCA

Conducting LCA requires a lot of data collection for the life cycle inventory. The data required might not be available or may be subjective to the study. Therefore consistency and standardization of data collection process is a good starting point to conduct LCA. Below is the list of limitations of doing LCA.

- The nature of choices and assumptions made in LCA(eg system boundary setting, selection of data sources and impact categories) may be subjective.
- Models used for inventory analysis or to assess environmental impacts are limited by their assumption, and may not be available for all potential impacts or application.

- Results of LCA studies focus on global and regional issues may not be appropriate for local applications.
- The accuracy of LCA studies may be limited by accessibility or availability of relevant data or by data quality.
- The lack of spatial and temporal dimensions in the inventory data used for impact assessment introduces uncertainty in impact results. This uncertainty varies with the spatial and temporal characteristics of each category.
- The LCA focuses on physical characteristics of the industrial activities and other economic process. It does not include market mechanism or secondary effects on technological development.

LCA does not offer total solution as it cannot access human and environmental safety and does not address comprehensive environmental management. Hence LCA by itself is insufficient for decision making.

2.7 Benefits and Uses of LCA

Despite the limitations of LCA, there are also many uses and benefits of studying LCA. It can be used by governments, private firms, consumer organizations and environmental groups as a decision support tool (Wenzel et al.1997, Krozer and Vis, 1998; Field and Ehrenfeld, 1999) for improving, developing, marketing and comparing products.

According to ISO 14040, the applications of an LCA can assist in:

- Analyzing the contribution of the life cycle stages to the overall environmental load aimed at prioritized improvements on products or processes.
- Identifying opportunities to improve the environment aspects of products at various points in their life cycle.
- Decision making such as strategic planning, priority setting and product or process design or redesign in industry, government organization and private sector.
- Comparing between products for internal or internal communications.

- Selecting the relevant indicators of environmental performance, including measurement techniques.
- Marketing
- Compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle.
- Assessing the potential environmental aspects and potential aspects associated with a product or service by compiling an inventory of relevant inputs and outputs evaluating the potential environmental impacts associated with those inputs and outputs.
- Interpreting the results of the inventory and impact phases in relations to the objectives of the study.

2.8 LCA Software

LCA computer software is very important because it can handle thousands of figures in carrying out a LCA analysis. There are many software tools available; some are in development stage and some are available in different languages other than English. But the most common software tools used widely by industries are SimaPro, Umberto, GaBi and TEAM.

2.8.1 SIMAPRO (System for Integrated Environmental Assessment of Products)

Simapro (Product Ecology Consultants, 1996) is a proven, reliable and flexible tool used by major industries, consultancies and universities. It is a professional tool used for assessment of products, processes and services. It was first released in 1990 and continues to be the most successful LCA software worldwide with nearly thousand user licences sold in 50 countries. Simapro will be used in this project to analyze the UPW production in a wafer fabrication plant. There are many available software versions but Simapro version 5.1 will be used in this project.

Advantages

- User friendly interface following ISO 14040.
- Easy to use with wizards to assist

- Parameterized modeling with scenario analysis
- Hybrid LCA with input output databases
- Direct linking to excel or ASP databases
- Direct impact assessment calculations from each stage of the model.

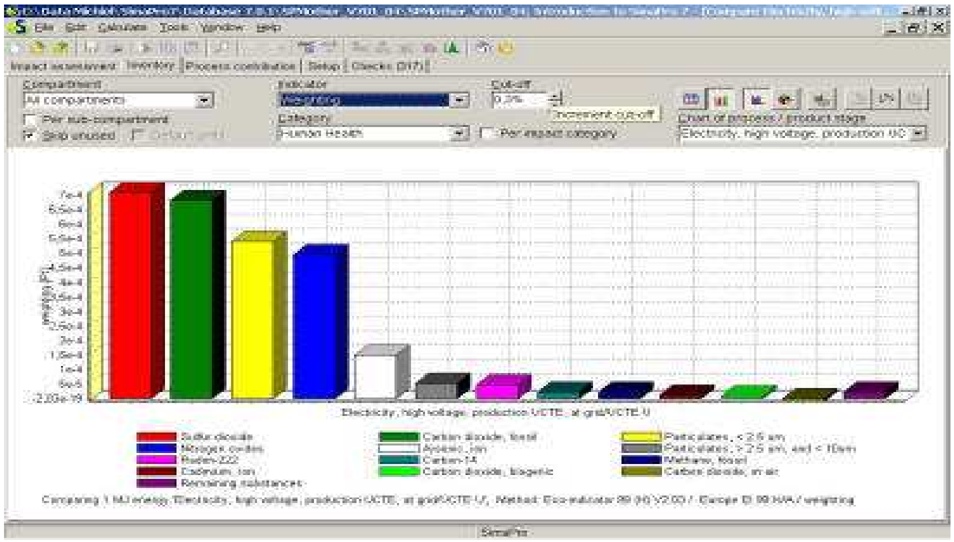


Figure 2.2: Sample of SimaPro result

2.8.2 Umberto

Umberto (1998) is a software tool to model, calculate and visualize material and energy flow systems. It is used to analyze the process systems or a product life cycle. It is used by companies that wish to optimize the processes and improve their competitiveness. It is also a flexible and versatile tool for research institutions and consultancies.

Advantages

- Complex structures can be modeled with its comfortable graphic interface.
- Results can be valuated using economic and environmental performance indicator.
- Cost data for materials and processes can be entered to support decision making.

2.8.3 Gabi

Gabi (PE International, 1989) is a software tool for build up life cycle balances covering both environmental and economical issues. Gabi software system has been used for the past few years and supports ISO 14040 standards.

Advantages

- It simplify the communication results
- It supports large amount of data within the product life cycle.
- It is able to calculate and aggregate the results.
- It is fast and compatible with other GaBi versions.

2.8.4 TEAM

TEAM (Ecobilan, 1990) is a powerful and flexible LCA software that allows the user to build and use a large database to model any system representing the operations associated with products, processes and activities. It is able to speed up the process of carrying out LCA studies by powerful calculation capabilities compliant with ISO 14040 series of standards.

Advantages

- It can speed up the process of carrying out a LCA compliant with current methodology standards by offering powerful calculation capacities, linked to a comprehensive process and material database.
- It is able to conduct LCA determinations using one of the protocols incorporated within the software.
- It can perform sensitivity analyses in an automated fashion to identify “data hot spots”.

2.9 LCA on Water

The purpose of the literature review is to show the path from the extraction of the raw materials to the production of the materials and components used by the product. It also acts as a guide to do the life cycle assessment of a product according to ISO14000. Two case studies carried out are LCA of drinking and waste water treatment system of Bologna city and LCA of water treatment process water urban system in South Africa.

2.9.1 Case study 1: LCA of Drinking and Wastewater Treatment System of Bologna City

An LCA study of existing water treatment plant had been done in Bologna City, Mexico (Tarantini, 2001), to compare the impacts to the environment and make improvement to the current system. Funded by the European Union, AQUASAVE project have to find means of reducing water consumption, collecting rainwater and recycle waste water by using appropriate equipments, devices and technologies.

The functional unit is the quantity of freshwater supply for domestic use per person in Bologna and treatment of waste product. It is estimated that per person consumes 180Lt/day. Team 3.0 software was used in this LCA study. The system boundaries include the process of distribution and treatment of drinking and waste water. No changes in the Life Cycle Inventory as they are assumed to be the same for the future system. Assumption was made inevitable, for the city was supplied by 6 water sources and all the waste water channeled to a treatment plant. Chemicals were excluded in the inventory as the proportion is small.

The main source of drinking water supply for Bologna city comes from the groundwater. The process of treating the groundwater starts with disinfecting the water followed by filtering and carbon activation. Most of Bologna city domestic waste water, city drains and some industrial waste water leads to the sewer and reached the waste water treatment plant. Solid waste will be incinerated but most of the treated waste water will be dispersed to the canal.

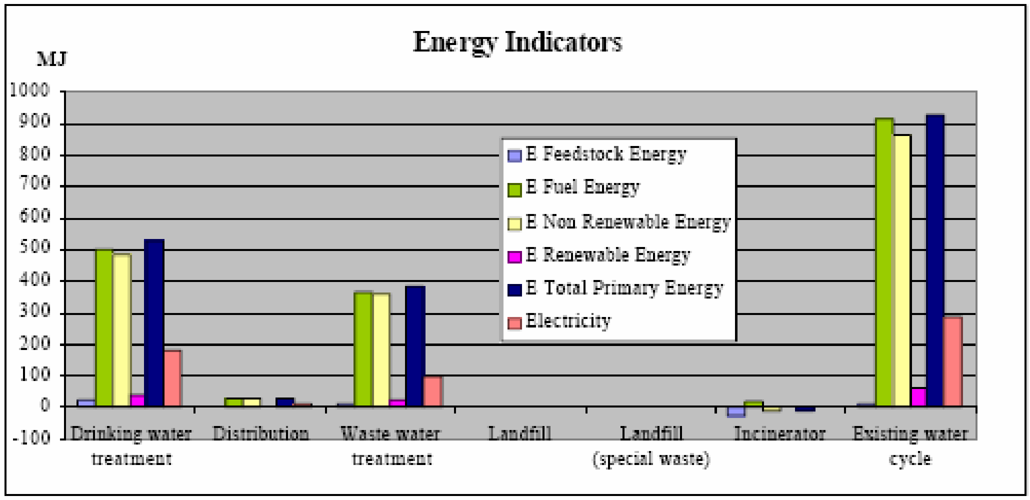


Fig 2.3: Energy Contributions from different process

The result for the energy contribution shows that treating water for drinking consumes the highest energy. The energy pattern is almost the same for waste water treatment except for the energy consumed is lower. The demand for electrical energy is related to the pumping of water in the plant.

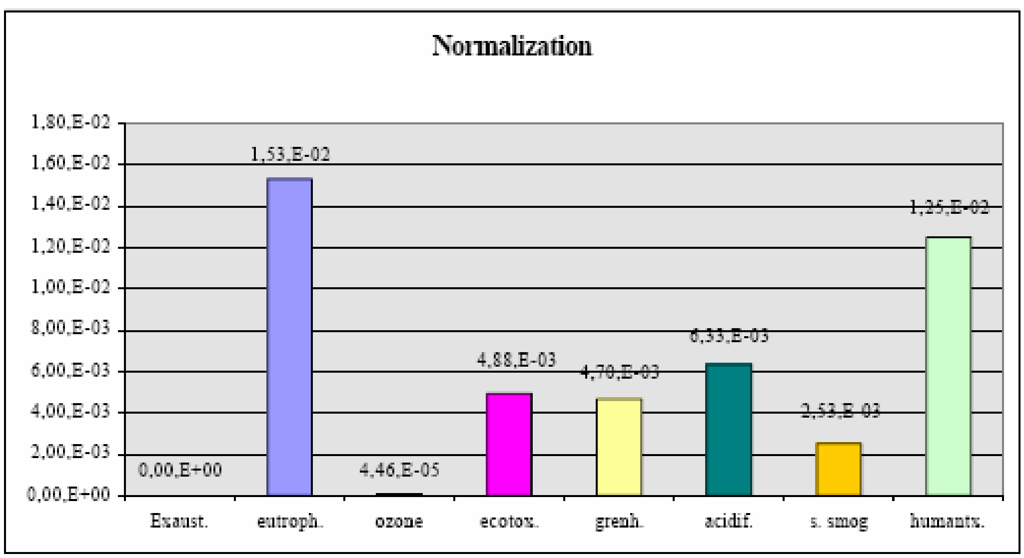


Fig 2.4: Environmental Impact under Normalization

The table above shows the environmental impact of the drinking and waste water treatment plant in Bologna city. After analyzing the environmental impact assessment, the production of electrical energy used to pump the water on site is identified as the highest contribution to the process. A well managed WWTP can reduce the eutrophication potential to an acceptable value compared to an average emission of a European citizen. The result also indicate further improvements can be made to the current water cycle by reducing the energy consumption, optimizing design and operation of pumping devices.

2.9.2 Case study 2: Environmental Life Cycle Assessments for water treatment process – A South African case study of an Urban Water Cycle

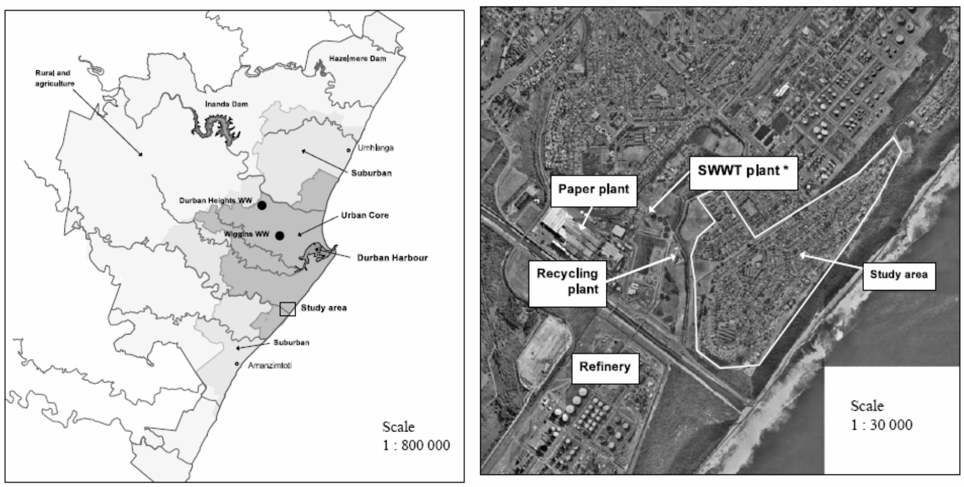


Fig 2.5: Locations of dams, waterworks and study area within the eThekwini Municipality

LCA methodology was employed to investigate and improve a local water system in eThekwini Municipality, South Africa (Friedrich, 2007) which has a population of 3.1 million and covers an area of 2300km^2. The LCA study on the urban water cycle have been conducted according to ISO 14040 standards. The whole recycling process is done in context of water scarcity in the catchment area where demand exceeds supply. The overall goal of this study is to provide information on the environmental burdens of an anthropogenic water path in an urban context in South Africa. This include the environmental impacts in the treatment, distribution, collection, recycling and disposal of water and waste water as well as the comparison for the provision of raw water and recycled water. The functional unit was 1 kl of treated water with all the losses in the process taken into account. Variations in the quality of raw water have also been taken into account. Assumptions had to be made with regard to the boundaries of the system such as not including the dams, contribution less than 0.5% for treatment process, data on pump and piping material used and storm water quantity. These limitations were considered acceptable as the sensitivity result shows minimum effect.

The inventory and impact assessment calculations were done using GaBi 3 software. Data were collected from different sources coming directly from the chemicals and energy used in the treatment plant and assistance from technical personnel. Data from potable water production from both waterworks were calculated for supply of 1 kl potable water in the entire eThekwini Municipality. The total energy used for the distribution of potable water and waste water collection system by all pumping station in the Municility were taken into account. Pipes and pumps material data were ignored due to lack of an accurate and complete inventory. The processing inputs such as chemical used, the individual specific manufacturers and data manufacturing processes are included. European data had to be used with imported data in GaBi 3 format. Data were collected and aggregated for 3 year period.

The impact assessment resulting from the input and output from the inventory translate the contributions to environmental problems and human health. The CML methodology was used to categorize the environmental impact from the calculated scores even though there are some limitations.

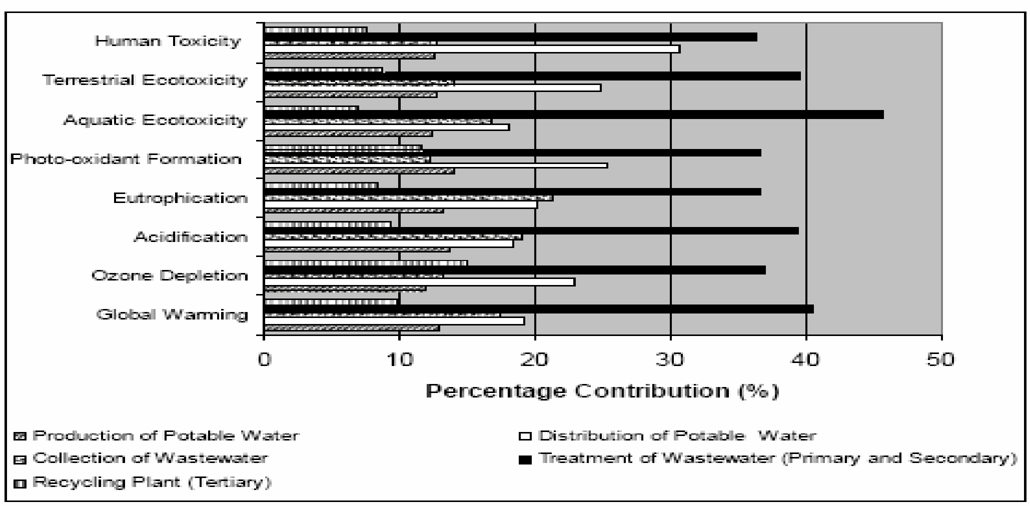


Fig 2.6: Environmental Impact Categorization by process

The results above interpret the contribution of individual processes with the aim of identifying the process with the highest contribution. The highest contribution for all environmental impacts is the treatment of wastewater followed by distribution of potable water and collection of waste water. The lowest contribution comes from the recycling plant which is more environmental friendly than treatment of raw water. Therefore it is recommended to supply recycle water to industries located near waste water treatment plant. Using recycled water reduces the need for treatment and distribution of raw water and help in preserving the scarce resource of the country.

In the LCA result below, the use of electrical energy carries the highest environmental burden due to coal consumption in generating electricity. As in previous case study, it is common that electricity in water system is the main contribution to environmental problem. To improve the overall environmental performance, the electricity consumption for each phase in the system has to be examined. Technically, electricity usage can be reduced for treatment of raw water and ozonation. Beside that, reducing consumer demand and supplier demand also helps. Supplier demand can be influenced by reducing leaks, removing illegal connection, reduce excess pressure in the system and using instruments as water tariffs. Consumer demand can be influenced by installing water saving devices and imposing laws on water restrictions.

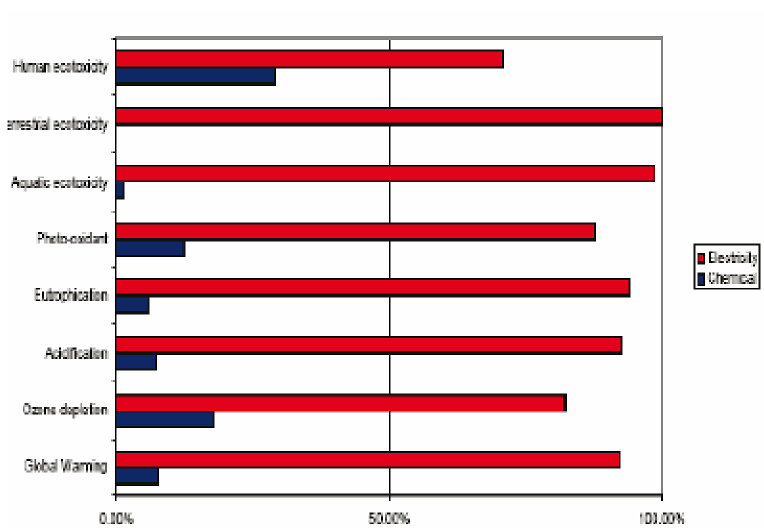


Fig 2.7: Electrical and chemical contribution to the environmental scores of the system

In conclusion, system and process approach are valuable in priortizing improvements and make desired changes due to different process ownership. From the result of the LCA, the highest contribution to the environment is the treatment of waste water. This proves that energy in the urban water system is the most important factor impacting the environment. Energy efficiency is linked to the pumping requirements of the system and conditions such as distance and elevation. In order to save energy in South Africa, recycling operations should be encouraged as there is demand for industrial grade water in the vicinity of waste water treatment plant.

CHAPTER 3

UPW Technology

3.1 Introduction

The functional unit of the LCA, which is the UPW plant and its manufacturing processes is explained in this chapter. It also includes the uses of UPW in a semiconductor foundry and the product requirements in manufacturing process of ultra pure water technology.

A lot of effort and time was spent to understand the manufacturing process flow through facility engineers and vendors. Discussions and meetings were conducted on this process aspect of this LCA study. The scope of work includes 2 different sites and companies in order to have a better data results and understanding. The RO plant is located at Numonyx Pte Ltd and the UPW plant is located at STMicroelectronics Pte Ltd. In STMicroelectronics, the UPW plant consisted of primary and polish loop as shown in appendix 1, supplying UPW to wafer fabrication plant producing 6” wafers.

3.2 Water Sources in Singapore

Singapore is recognized for its sustainable water management. Our 4 national taps strategy supplies us with diversified and sustainable supply of water. The 4 taps are: water from local catchments, imported water from Malaysia, NEWater and desalinated water.

New man made reservoirs are going to be made to increase the supply of raw water. The reservoirs would be useful after it is built. There would be different water sports available when opened to the public. These reservoirs would also control flooding. If too much water comes in, flood gates would open to allow water to flow out. One concern is pollution if this water is going to be used for drinking and other activities.

Desalinated water used in Singapore refers to sea water that has been through a process that extracts pure water from the ocean water. Seawater is treated with some chemicals that cause the impurities to group in large groups to be removed more easily. Air is injected to allow lighter particles to float and be removed. The water is filtered through sand and put through Reverse Osmosis and then remineralised. Finally, it is blended with the reservoir water before being sent to homes and industries.

Singapore made two treaties with Malaysia concerning raw water agreement, the first one expiring in 2011 and the second in 2061.Currently Singapore is buying raw water from Malaysia and selling treated water to them at a higher cost. Malaysia is planning to change the terms of the agreement when it expires in 2011. No solution to both side have been given, so this is not a long term stable source of water anymore.

Newater is reclaimed water which has gone through treatment in NEWater Plants which consists of four processes namely Micro Filtration, Reverse Osmosis, Water Conditioning and Ultraviolet Disinfection before turning into pure water. It can be used for potable and non-potable purposes mainly used for wafer fabrication and air condition cooling towers. The total capacity of the newater plants supplying to wafer fabrication in Singapore is 92,000m3/day which is 33,580,000m3/year.

Besides supplying Newater to wafer fabrication and other commercial hubs, Newater is also pumped to the reservoir, equivalent to 1% of the reservoir size. The need for NEWater supply is due to Singapore's daily water consumption keeps increasing. Singapore's population is increasing and economy is growing, more water is needed to keep factories running and people living. Another reason is to cover the loss of Malaysia water in order to be self sufficient.

The Singapore Government increases the price of water in an attempt to make Singaporeans conserve water, since water is a scarce resource in Singapore. The immediate consequence of increasing the price of water is probably a decrease in the quantity demanded of water – assuming demand for water is normal. In conclusion, water is a basic and essential necessity and people will still have to consume it even if the price increased. Thus, the quantity demanded of water will probably not drop drastically. It may even increase in the long run if Singapore's population grows even faster than what the water supply can cope with.

3.3 Definition and Application of UPW

Ultra Pure Water (UPW) is widely used by manufacturing company especially in the semiconductor foundry in the process of wafer fabrication. UPW is made up of raw water being pressurized through a semi permeable membrane and passing through UV sterilizer treatment. After passing through the UV sterilization process, the treated water is further treated by removing $CO2$ and $O2$ from the water by membrane degasifier. After removing the unwanted gas in the water, the next step is to remove TDS and silica in the water by separating the ions. To further remove TDS and silica, the treated water is passed through a resin mixed bed before going through the final filter.

UPW is used in wafer production process such as wet cleans, wet process in etching and diffusion, solvent process and chemical mechanical planarization(CMP) and rinses. The amount of UPW use in the fab can vary widely depending on the wafer input, size and process recipe.

Fig 3.1: Semitool spin rinse dry

Semitool equipments used lots of UPW to rinse the wafer surface of chemical and then dry with nitrogen by spinning.

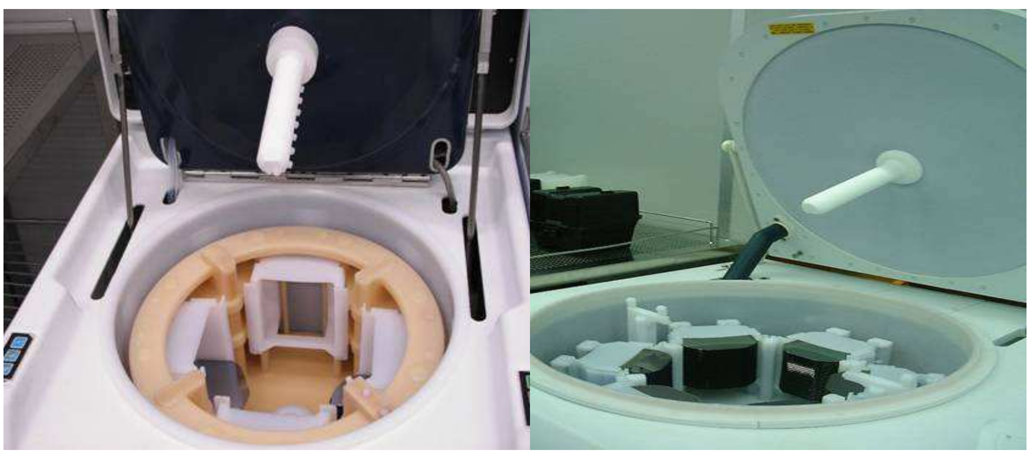


Fig 3.2: Acid Processors

The two pictures above are acid processors machine which mainly uses chemical for processing and can be found in diffusion and etch wet process. The UPW is mainly used for cleaning the machines and flushing the waste chemical and UPW in the drain to reduce the pH value.

Fig 3.3: Chemical Wet Bench

This machine also uses a lot of UPW to rinse acid from the wafer surface by dipping it from 1 bath tank to another. This machine can be found in all wet process in the fab. Basically most of the wet process in diffusion, etching, epitaxy, and CVD areas uses UPW for cleaning, process and flushing.

Fabs often produce their own UPW from local feed water. In general, 1,400-1,600 gallons of city water is needed to produce 1,000 gallons of UPW. Purity of UPW is important because a molecule of contaminant can cause certain process nonfunctional. Contaminants include particles, organic compounds and dissolved ions and gases.

3.4 UPW Requirements in STMicroelectronics Pte Ltd

3.4.1 Feedwater Specification

Water from Numonyx Pte Ltd RO Product water storage tank serves as the water supply source for STMicroelectronics Pte Ltd 6" fab. The following table gives details of the RO product water characteristics:

Chemical & Physical Characteristics (in mg/l where applicable)	RO Product Water from Numonyx Pte Ltd
pH value	7-8.5
Conductivity (uS/cm)	4-5
Taste	Unobjectable
Odor	Unodjectable
Total Alkalinity (CaCO3)	20 ppb
Total Hardness (CaCO3)	20 ppb
Chloride (Cl)	1 ppm
Sulfate (SO4)	0.5 ppm
Silica (SiO2)	20 ppb
Sodium (Na)	0.5 ppm
TOC ppb	9-10

Table 3.1: RO water specifications

3.4.2 Product Water Specification

The UPW production system is designed to produce water of the following quality. These standards are continuously monitored by SPC as the quality of UPW is one of the top priorities in a wafer manufacturing plant.

Parameters	Units	Specifications
Resistivity @ 25°C	MΩcm	>=18.0
Temperature, Cold DI	°C	23°C ± 1°C
Pressure @ POU	bargainable	4.2 ± 0.5
TOC	ppb	<=5
Particles counts >0.05 µm N/l		Less than 1000
Particles counts >0.10 µm N/l		Less than 100
Bacteria count	CFU/liter	<=1
Total Silica	ppb	<=5
Dissolved silica	ppb	<=2
Oxygen	ppb	<10
Fe	ppt	<50
Zn	ppt	<50
Cu	ppt	<50
Ni	ppt	<50
Al	ppt	<50
Mg	ppt	<50
K	ppt	<50
Na	ppt	<50
Ca	ppt	<50
Cl	ppt	<50
SO4	ppt	<50
F	ppt	<50
NH4	ppt	<50
B	ppt	<50

Table 3.2: UPW specifications

3.4.3 Flow Capacity and Operation Mode

Primary System : 120 m3/hr
Polishing UPW Loop : 105 m3/hr
Continuous Operation Mode : 24 hrs/day @ 7 days/week

3.4 Manufacturing Process of UPW

Step 1: RO system in Numonyx Pte Ltd

Fig 3.4: HERO system

Uninterrupted supply of high purity water is essential for each fab operation especially 8" wafer production. The high tech UPW plant in Numonyx Pte Ltd is commissioned on year 2000 and it serves not only Numonyx plant but also 6" wafer production plant in STMicroelectronics Pte Ltd. To meet the increasing demand for RO water by both plants, the conventional RO system has been upgraded to the high efficiency RO (HERO). The raw material for HERO system comes from the city water. The feed water will be pressurized through a semi permeable membrane, only clean water will pass through leaving impurities which are too big to be flushed away. RO mainly removes the hardness, particle, Total Organic Caron (TOC) and Boron. HERO RO can be operated at high pH and due to this, weak acid get ionized and rejected in the RO system. Therefore TOC and Boron rejection is very high in this HERO RO. The overall efficiency of HERO RO is 95% whereas the efficiency of conventional RO is 85%. Since the HERO RO is operating at high pH, there is no requirement for RO cleaning and thereby down time for maintenance not required. Centrifugal pumps are being used to transfer the RO water to 6" plant and the pumps are being sent out for annual maintenance. For energy saving purpose, all the RO pumps have Variable Frequency Drive (VFD).

Step 2: Primary Loop in STMicroelectronics consisting of Storage Tank, Transfer Pumps, UV Sterilizer and Membrane Degasifier

Fig 3.5: RO water tank

The transferred RO water will be stored in a 75 cubic meter nitrogen blanketed permeate water storage tank before being delivered downstream for further treatment. The tank is located at level 1 beside the UPW plant and the tank is equipped with level transmitter to monitor the level in the tank.

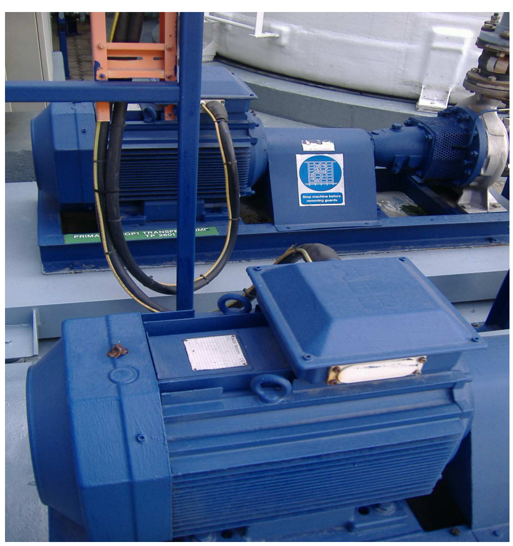


Fig 3.6: RO water transfer pumps

The primary system operates by taking water from the RO water storage tank and boosting the pressure with 2 RO transfer pumps equipped with variable frequency drives (VFD). There is normally 1 pump on line and 1 pump in standby. The pump is continuously running providing 133 m3/hr of flow to the primary system unless low-low level is detected in the RO water storage tank. The pump run at set pressure. If the effluent pressure drops below the setting pressure, the control function will automatically increase the VFD speed. If the effluent pressure is higher than the setting pressure, the control function will automatically decrease the VFD speed.

Fig 3.7: TOC destruct UV

RO treated water is directed through a train of ultraviolet sterilizers. The sterilizer is provided with 185 nanometer lamps to remove the remaining Total Organic Carbon (TOC) in the primary process water. The sterilizers system runs continuously on line providing 133 m3/hr of sterilized water to the membrane degasifier system.

Fig 3.8: Membrane Degasifier

Treated water is passed through a set of membrane degasifier trains to remove virtually all the dissolved gases (CO_2, O_2) in the process water. The membrane degasifier runs continuously on line providing 133 m3/hr of product water to the CDI system. There are 3 vacuum pumps with 2 running and 1 in standby connected to the degasifier system. Flow switches continuously confirm chilled water flow in their respective vacuum pump recirculation system. N_2 is used as the sweeping gas in the system. Vacuum pumps are used to remove the dissolved gases to the exhaust. Chilled water is used in heat exchanger to remove excess heat from the gases and condensate it into liquid.

Fig 3.9: Vacuum pumps

Step 3: Polish Loop in STMicroelectronics consisting of CDI, Mixed Bed and UF.

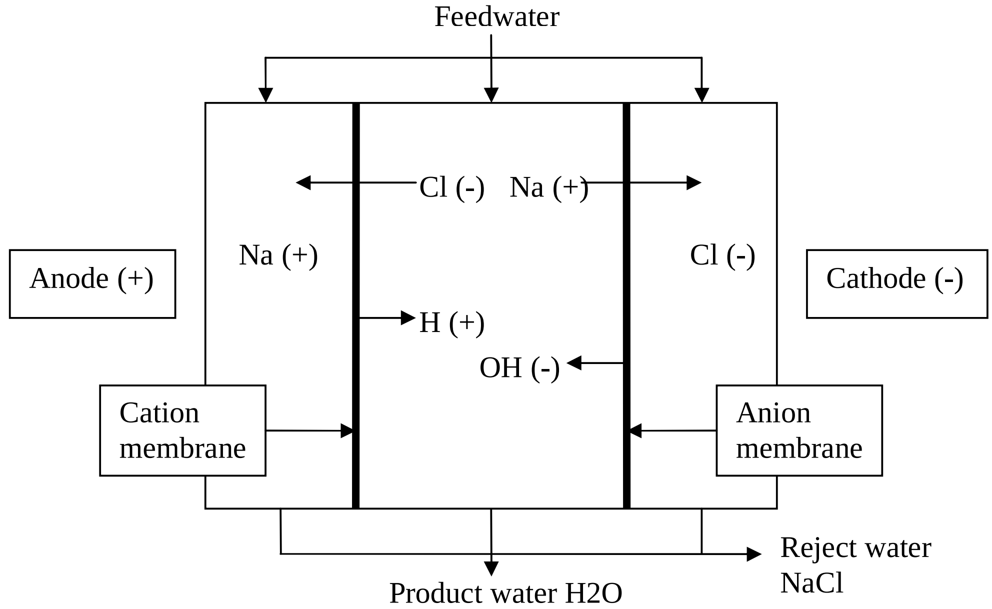


Fig 3.10: Continuous De-ionized unit

RO treated water subsequently passed through 4 trains of continuous deionization unit for further removal of Total Dissolve Solid (TDS) and silica. There are 2 P-serial CDA and 2 LX serial CDI. It is a continuous process to produce high purity water by using ion-selective membrane, ions exchange resins and electricity. Direct Current (DC) electric potential is the driving force for removing ions from the feed stream while continuously regenerating the resins. RO feed water conductivity entering each module must be less than 40 µS/cm. The feed water flows parallel to the membrane surface in the compartment. Resins capture dissolved ions. Electric potential drives capture cat-ions through the cat-ion membranes and the anions through the anion membranes. Cat-ion permeable membranes transport cat-ion such as sodium ions out of the product compartment but prevent anions from leaving the reject compartment. Anion permeable membranes transport anions such as chloride ions out of the dilute compartment but prevent cat-ions from leaving concentrate compartment. Reject stream removes concentrated ions from the system. Product water leaves the system.

Fig 3.11: CDI Process

Fig 3.12: Resin Mixed Bed

Resin mixed bed is located in the polish loop. Loop de-ionized water (DIW) passes through a train of non-regenerable, mixed bed ion exchange vessels for further removal of the Total Dissolve Solid (TDS) and silica. 2 polish mixed bed exchangers are operated by lead lag configuration mode to achieve the required water specification. A resistivity line cell is installed at the individual mixed bed outlet. When the resistivity value reaches the exhaustion point, the exhausted mixed bed vessel will be isolated and the new resin will replace exhausted resin then put into service.

Fig 3.13: Loop UF Pre-filter

Fig 3.14: UF Final filter

In the polishing loop, the ultra pure water is initially filtered by a 1-micron cartridge filter before the final filtration. The ultra filtration (UF) product water is sent to the point of use while the UF reject water is directed back to the UPW tank. Ultra filtration is to remove smaller size particles in the water before distributing to the loop.

CHAPTER 4

METHODOLOGY

4.1 Introduction

The main objective of this project is to set up an LCA model in order to access environmental information on UPW plant. A literature review of LCA studies of waste water have been conducted as a guideline for the research.

Life cycle assessment was performed in accordance with methodology presented by Wenzel et al. (1997) that complies with the general principles of ISO14040 (ISO, 1997). SimaPro was used in this project to perform the inventory and impact assessment calculations. Data were collected from various sources. On site specific data have been collected for UPW production with supports from technicians and engineers, and the data was primarily from STMicroelectronics Pte Ltd in Singapore. The main data collected were identified by the specific manufacturer of the commercial products. Moreover, the raw material consumption and electricity usage were measured and derived from the plant's record.

Data was applied in Simapro after getting all the information and it will weigh the impacts for further improvement.

There are 4 basic steps to carry out LCA study, they are shown below.

1. Define the goal and scope of the study.
2. Create a model of the product with all the environmental inflow and outflows by using LCA software. This is called life cycle inventory stage.
3. Assess the environmental impact caused by the inflow and outflow, this is referred as Life Cycle impact assessment.
4. Lastly will be to interpret the results.

4.2 Defining the goal

The most important pitfall in the implementation of LCA turns out to be the lack of a clear definition of the purpose and application of LCA (Goedkoop, Schryver & Oele 2006).The aim of the study is to set up an LCA model to assess the environmental information of producing Ultra pure water in a wafer fabrication plant. The goal is obviously for further improvement of the system and reducing health hazards and safety risk in the process. Besides that, the goal is also to find out which process or products have the least environmental impact to the environment and what factors will cause environmental burden when producing UPW. The goal is the reason for carrying out the study as well as the intended application of the results and the intended audience.

Besides that, the goal of the study is to determine:

- Future improvement of the product or process so that can reduce the environmental impacts.
- The most environmental impacts caused by the product or process in each stage of its life cycle.
- The least environmental impacts caused by the product or process in each stage of its life cycle.
- The most important factors that decided the environmental load of UPW production.

4.3 Defining the scope

The scope describes the depth of the study and can fullfill the purpose with the actual extent of the limitations. The scope of an LCA should contain the following items described:

1) The function of the product system
2) The functional unit
3) The system boundaries
4) Allocation procedures
5) Types of impact assessment methodology and interpretation to be performed

6) Data requirements
7) Assumptions and limitations
8) Data quality requirements
9) Type of critical review, if any
10) Type and format of the report required for the study

The scope of this project covers the production of UPW in STMicroelectronics Pte Ltd. This includes the manufacturing process and production of RO water at Numonyx Pte Ltd to the supply of UPW to the wafer fabrication plant at STMicroelectronics Pte Ltd. The scope of the study involved the manufacturing process of UPW from the raw materials used in the plant up to the waste being produced.

1. Raw materials (materials used in the process of producing UPW)
    - Industrial City Water
    - Membrane
    - Nitrogen
    - UV lamps

2. Manufacturing process
    i. Reverse Osmosis – Industrial city water is pressurized through a semi-permeable membrane by big capacity pumps where only clean water is passed through leaving impurities to be flushed away. HERO system has high rejection of TOC and Boron that makes it 95% efficient. This is the stage where most of the electrical power is utilize.

    ii. UV sterilizing treatment – The water is passed through UV light to remove TOC further.

    iii. Membrane Degasifier – The water is passed through a membrane to virtually remove CO_2 and O_2. The N_2 is used as a sweeping gas to mix with other gases before going to exhaust.

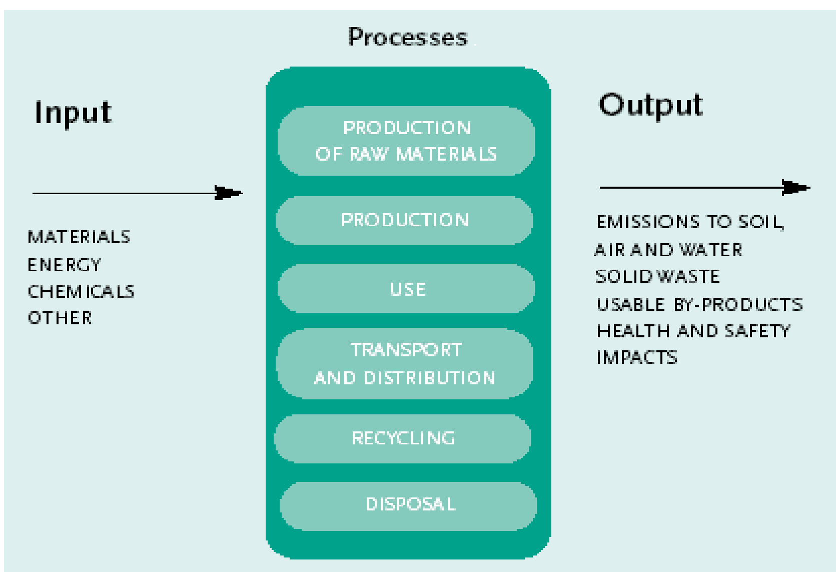
iv. Continuous De-Ionized – The water passes through a membrane electrically to separate the anion and cation leaving product water to pass through and rejecting NaCl.

v. Resin mixed bed – The water that passes through the mixed bed is to further remove the TDS and silica. The resistivity of the water is monitored to change the exhausted resins.

vi. Ultra Filtration – The water is filtered by a 0.2-micron cartridge filter and then 0.04-micron cartridge filter before sending to the point of use.

3. Waste water

- The reject water from UPW plant will be recycled through the loop and the used UPW from the fab will be treated with other waste water before discharging to drain.



(Source:mst, 2009)

Fig 4.1: Diagram showing input, outputs and processes in a product life cycle

4.3.1 Functional unit

The functional unit defined in this study is the UPW plant production, supplying flow rate of 130m3/hr to the manufacturing of wafer fabrication at 5000 wafers per day. Therefore the functional unit define is the plant as a unit designed and commissioned to manufacture 1,285,042 m3 of UPW in 1 year. The other functional unit must be standardized as in table 4.1

Name	Unit
Water	kg
Nitrogen	kg
Glass	kg
Electricity	kWh
Diesel	Lt

Table 4.1: Units standardization

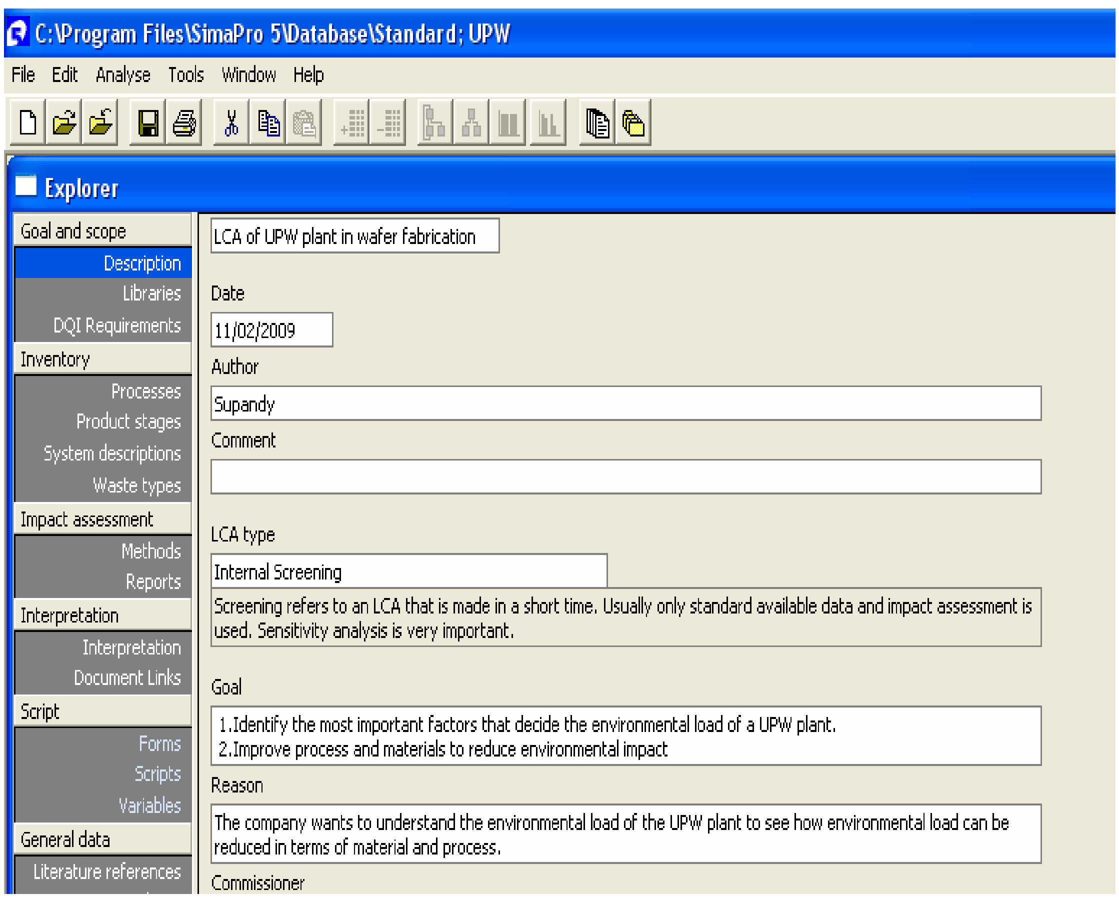


Fig 4.2: Screenshot of goal and scope definition in SimaPro

4.4 Inventory

In the inventory stage of an LCA, all emissions and raw material consumption data are collected and all the inputs and outputs data must be collected before making a model of the product life cycle. To perform a life cycle impact assessment with SimaPro, 3 major activities need to be done.

1. Collect the data not available in database and enter in process records.
2. Link process records to each other to form a process tree
3. Link process records in product stages to model the life cycle.

There are 5 categories in the process of LCA

- Material
- Energy
- Transport
- Processing
- Use
- Waste scenario
- Waste treatment

4.4.1 Materials used in the plant

The data not available in Simapro database are found in manuals, internet resources and interview with the UPW plant personnel. The most important data can be found form the company database consumption file and material data sheet. Visit to the plant and interview with the plant manager have been conducted to get more information. Below are the data provided by the plant manager, Mr S. Sivakumar.

UPW process equipment at the plant

UPW process equipment	Quantity on site
RO pumps	4 nos
RO membrane unit	4 units
RO membrane	8 nos/unit
Transfer pumps (37kW/2900RPM)	2 nos for primary loop 2 nos for polish loop
UV sterilizing treatment	12 units
UV lamps	36 lamps/unit
Membrane Degasifier	2 units
Membrane Housing	6 nos/unit
Vacuum Pumps (15kW,1450RPM)	4 nos (2 nos/unit)
CDI system	2 units
CDI modules	8 modules/unit
Mixed Bed tank	2 nos
Booster Pumps	4 nos

Table 4.2: Quantity of process equipment at the plant

Input material in a year

Material and energy	Quantity
Water (Industrial city water)	2,560,405 m3 at RO plant
RO water consume by STMicroelectronics	1,285,042 m3
Total UN2 used by UPW plant	7308 m3
UV lamps	Weight/unit = 600 grams/pc x 36 lamps/unit =21.6kg
RO membrane	Weight/unit = 60 kg/membrane x 8 membrane/unit = 480 kg
Degasifier membrane	30 kg
UF filter membrane	1 part

Acids (For lab analysis)	100Lt
Electricity at UPW plant in STMicroelectronics	4,866,793 kWh
Electricity at UPW plant in Numonyx	5,367,567 kWh
Diesel (Materials transportation)	2000 Lt

Table 4.3: Input material in a year

Output material in a year

Materials and Energy (Outputs)	**Quantity**
Production of UPW	1,285,042 m3
Waste acid (UPW and acid from production)	770,880 m3

Table 4.4: Output material in a year

4.4.2 Non-material consumption by process

Non-Material Process	**Electricity (%)**	**Electricity (kWh)**	**Water (%)**	**Water (m3)**	**Nitrogen (%)**	**Nitrogen (kg)**
RO process	40	2,147,026	100	2,560,405	-	-
UV treatment	30	1,460,037	25	321,260	20	1461.6
Membrane Degasifier	20	973,358	25	321,260	80	5846.4
CDI	25	1,216,698	25	321,260	-	-
Mixed Bed	25	1,216,698	25	321,260	-	-

Table 4.5: Electricity, water and nitrogen consumption

4.4.3 UV lamps break down by material

The UV lamps are changed after 8000 hours of use as recommended by the supplier. The weight of the lamp is about 600g and consists of electronics parts. The quartz sleeve is made of silicon and glass and weighs about 200g. The UV lamps are changed during PM if the light intensity is low and the quartz sleeve is clean. The weights of the different materials are in the table below.

Material / **Process Material**	**Silicon (%)**	**Silicon (kg)**	**Glass (%)**	**Glass (kg)**	**Electronics parts (%)**	**Electronics Parts (kg)**
UV lamps	80	69.12	20	17.28	100	259.2

Table 4.6: UV lamp and quartz sleeve material breakdown

4.4.4 Filter Membrane break down by material

Membranes are mainly used in UPW plant to filter unwanted particles, gases or other materials in order to provide good quality water. The 4 processes below uses membrane to filter specific materials and the size and weight varied. The RO membrane is the longest among all the membrane in UPW plant and total weight is 1920kg.

The membrane degasifier membrane contains thousands of microporous polypropylene hollow fibers knitted into an array that is wound around a distribution tube. The membrane is housed in a cartridge made form PVDF material and covered by stainless steel casing. The weight of a set of membrane is 30 kg and the total weight at site is 360kg. Table 6.7 shows the material breakdown by process for membranes.

Material / **Process Material**	**Cellulose Acetate (membrane) (%)**	**Cellulose Acetate (membrane) (kg)**	**Polypropylene for housing (%)**	**Polypropylene for housing (kg)**	**Stainless steel casing (%)**	**Stainless steel casing (kg)**
RO Membrane	30	576	20	384	50	960
	Polypropylene fibers (%)	**Polypropylene fibers (kg)**	**PVDF cartridge (%)**	**PVDF cartridge (kg)**	**Stainless steel casing (%)**	**Stainless steel casing (kg)**
Degasifier Membrane	35	126	15	54	50	180
	Ion-selective membrane (p)		**Ion exchange resins (%)**			
CDI membrane	16		50			
	Polysulfone (membrane					

	and casing) (%)					
UF filter membrane	100					

Table 4.7: Filter membrane breakdown by materials

4.4.5 Pump and motor break down by material

RO pumps at Numonyx are the biggest in the site and used to pressurize the water through the semi permeable membrane. The pump rated at 45kW weighs 570 kg and the total weight of all the pumps are 2280 kg. Table 6.8 shows the different process pump and motor weight.

RO pumps Item weight (kg)	
Motor	300
Pump	270
Transfer & Booster pumps Item weight (kg)	
Motor	200
Pump	148
Vacuum pumps Item weight (kg)	
Motor	120
Pump	80

Table 4.8: Different pump and motor weight

Material **Process Material**	**Grey Cast Iron (EN-GJL-250(%)**	**Grey Cast Iron (EN-GJL-250)(kg)**	**Stainless Steel (X6CrNiMoTi17-12-2 (%)**	**Stainless Steel (X6CrNiMoTi17-12-2 (%)**	**Stainless cast steel (GX4CrNiMo19-11) (%)**	**Stainless cast steel (GX4CrNiMo19-11) (kg)**
RO pumps	50	135	25	67.5	25	67.5
Transfer/ Booster pumps	50	74	25	37	25	37
Vacuum pumps	50	40	25	20	25	20

Table 4.9: Different pump materials by process

Material / Process Material	Grey Cast Iron (EN-GJL-250(%)	Grey Cast Iron (EN-GJL-250)(kg)	Copper wire (%)	Copper wire (kg)	Stainless cast steel (GX4Cr NiMo19-11) (%)	Stainless cast steel (GX4Cr NiMo19-11) (kg)
RO motor	50	150	25	75	25	75
Transfer/ Booster motor	50	100	25	50	25	50
Vacuum motor	50	60	25	30	25	30

Table 4.10: Different motor materials by process

Total weight of the different materials

Total weight of cast iron for RO pump and motor = 135 + 150 = 285kg

Total weight of stainless cast steel for RO pump and motor = 67.5 + 75 = 142.5kg

Total weight of cast iron for transfer/booster pump and motor =74 + 100 = 174kg

Total weight of stainless cast steel for booster/transfer pump and motor = 37 + 50 = 87kg

4.5 Conducting a Sima-pro Analysis of UPW plant

Step 1: **Data Quality Requirements**

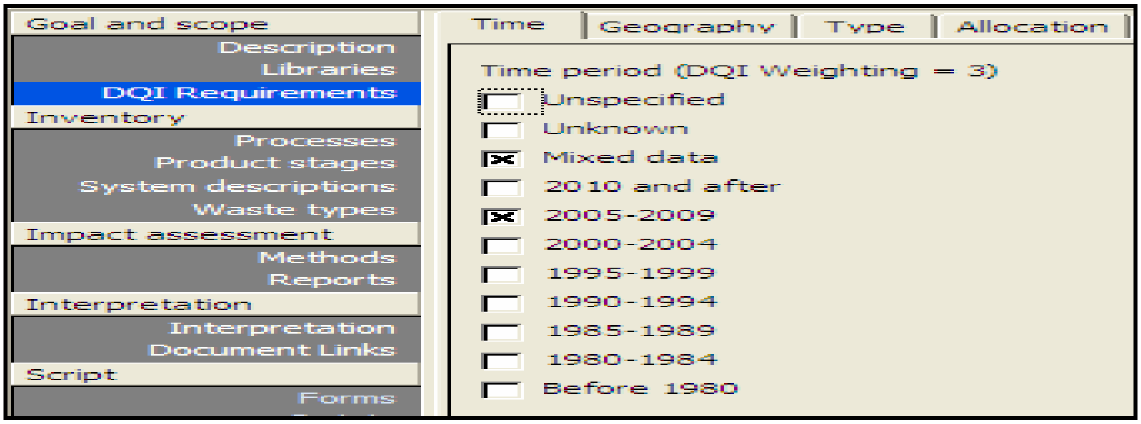


Figure 4.3: Time DQI

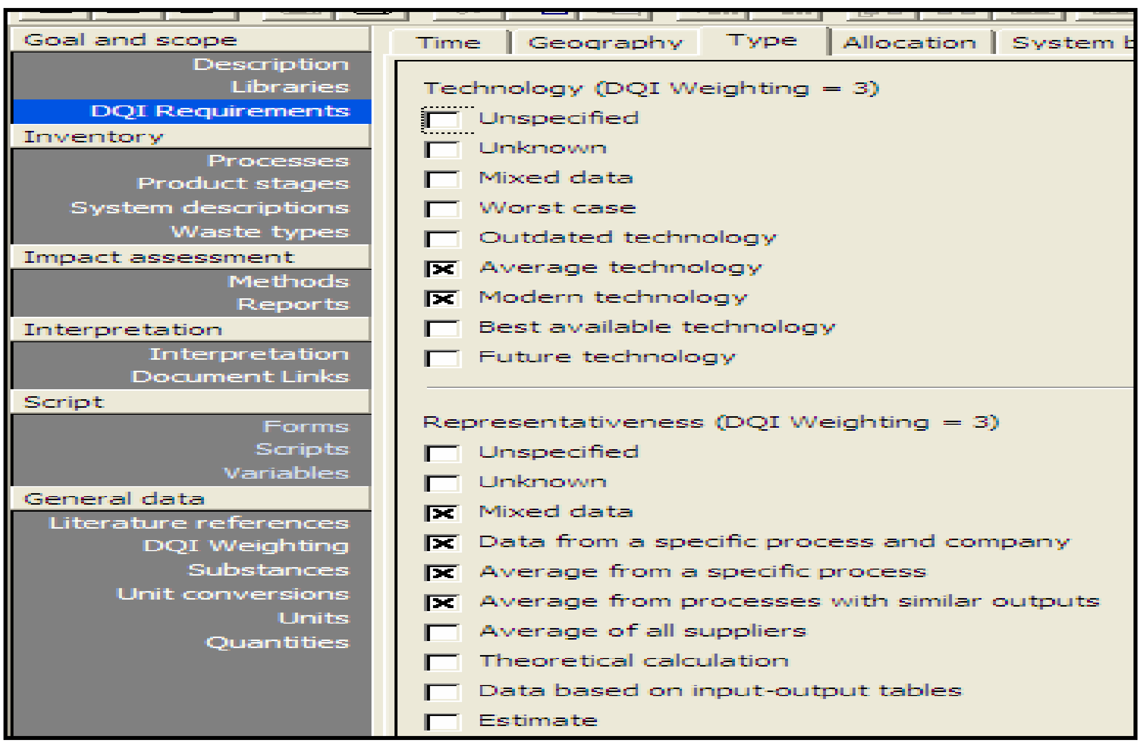


Figure 4.4: Type DQI

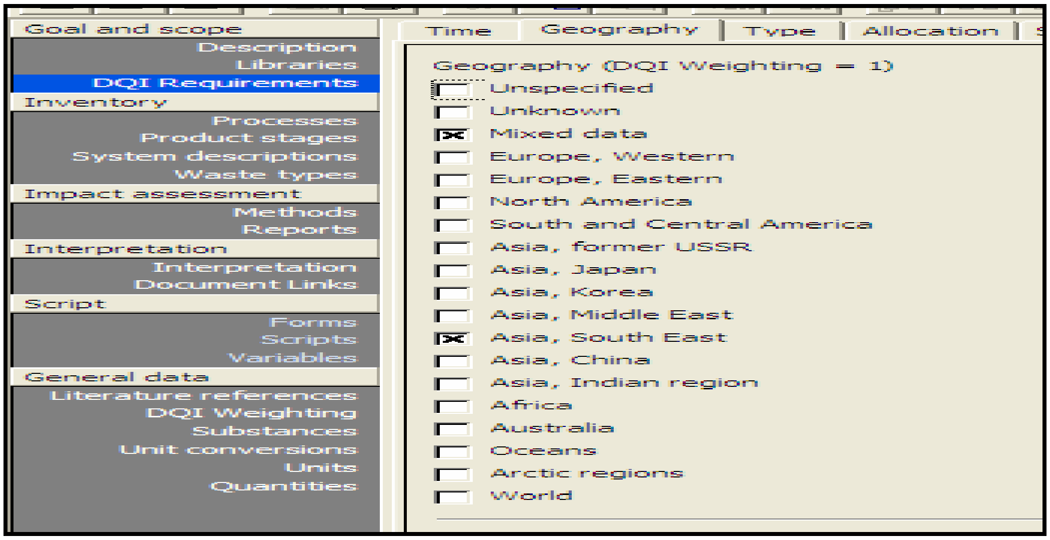


Figure 4.5: Geography DQI

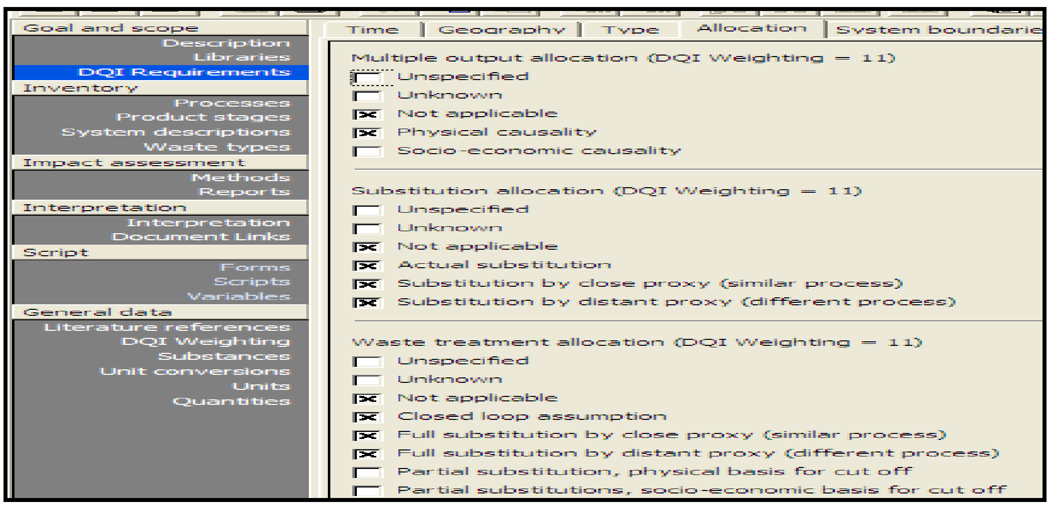


Figure 4.6: Allocation DQI

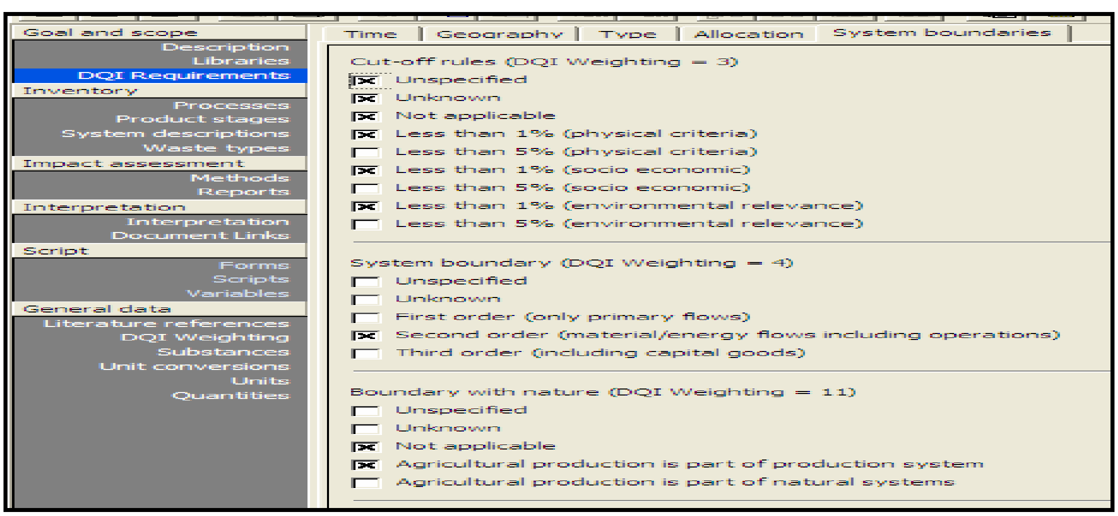
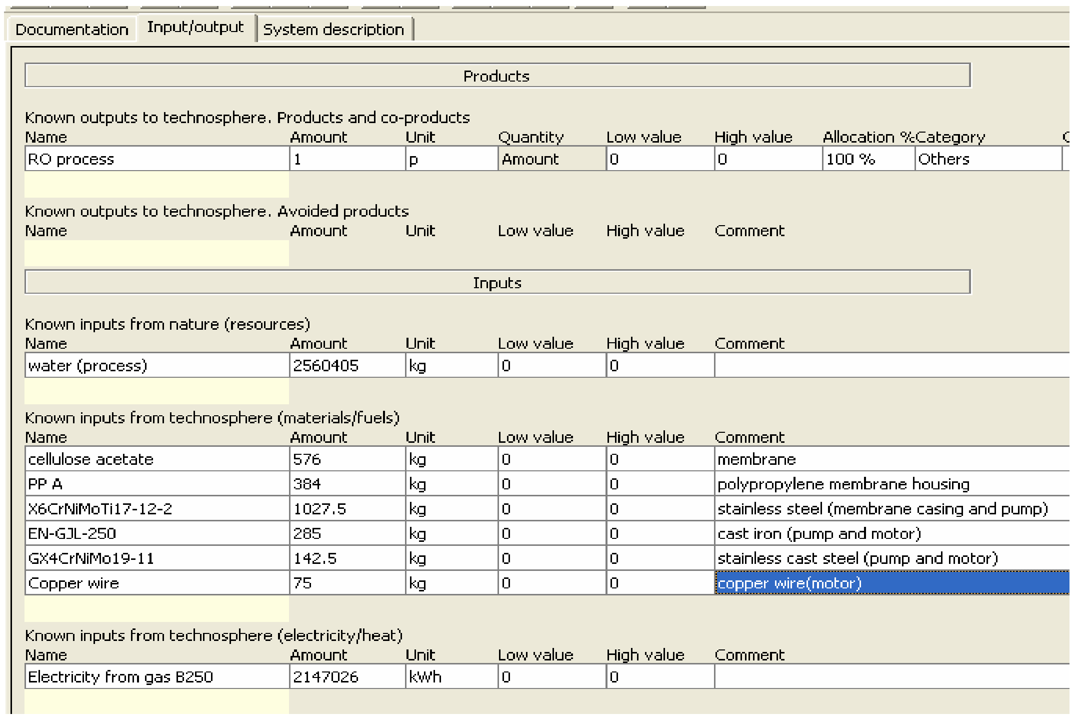


Figure 4.7: System Boundaries DQI

Step 2: **Analyse the RO system process in Numonyx**

Water from the industrial city water pipeline is the basic material used in producing UPW. Lots of water is needed at the RO plant to supply both 6" and 8" plants. The RO water is pumped to the RO tank located at the UPW plant in STMicroelectronics. Below are the inventory inputs to SimaPro.



Documentation | Input/output | System description

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Low value	High value	Allocation %	Category
RO process	1	p	Amount	0	0	100 %	Others

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Low value	High value	Comment

Inputs

Known inputs from nature (resources)

Name	Amount	Unit	Low value	High value	Comment
water (process)	2560405	kg	0	0	

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Low value	High value	Comment
cellulose acetate	576	kg	0	0	membrane
PP A	384	kg	0	0	polypropylene membrane housing
X6CrNiMoTi17-12-2	1027.5	kg	0	0	stainless steel (membrane casing and pump)
EN-GJL-250	285	kg	0	0	cast iron (pump and motor)
GX4CrNiMo19-11	142.5	kg	0	0	stainless cast steel (pump and motor)
Copper wire	75	kg	0	0	copper wire(motor)

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Low value	High value	Comment
Electricity from gas B250	2147026	kWh	0	0	

Figure 4.8: SimaPro Inventory inputs for RO process

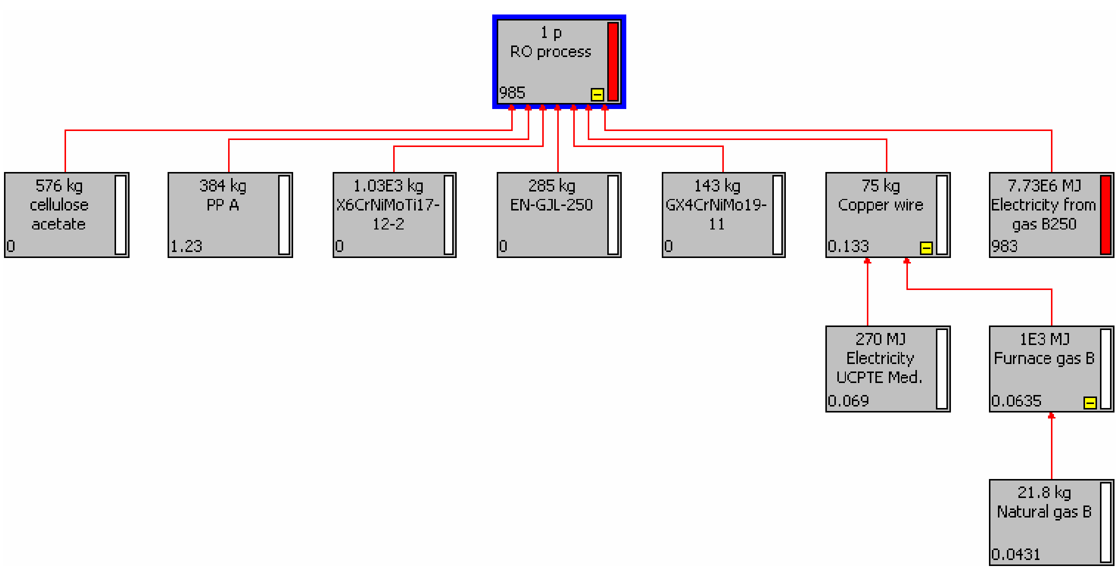
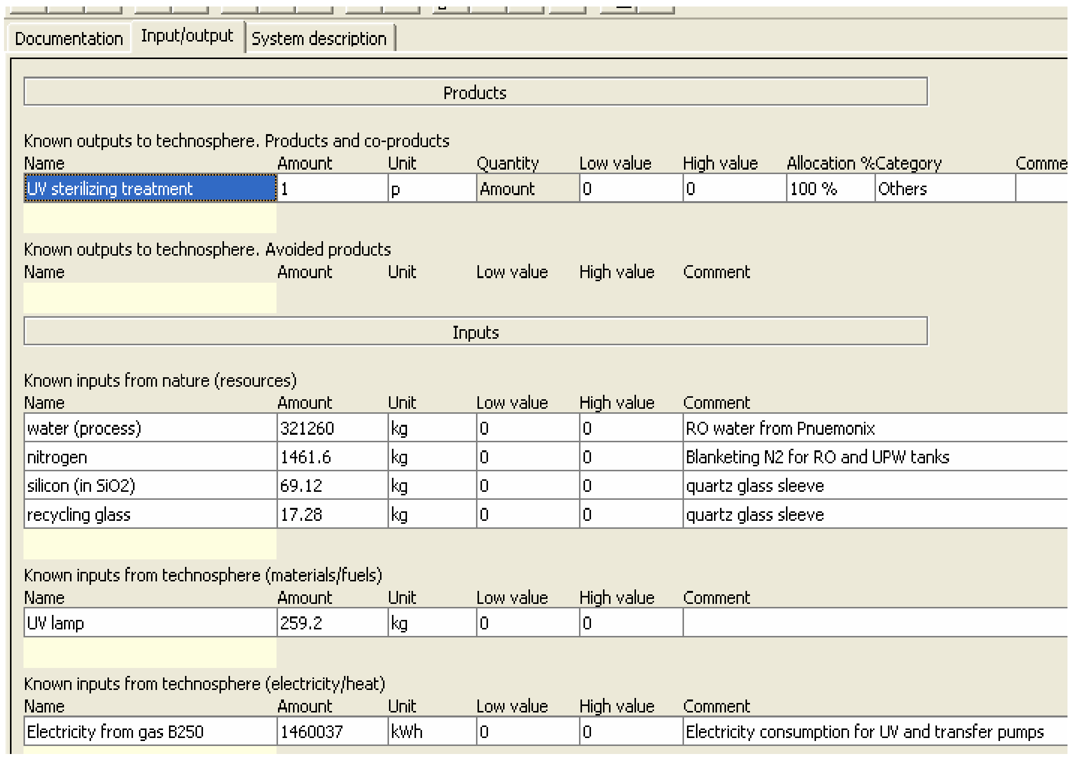


Figure 4.9: SimaPro Tree for RO process

Step 3: **Tanks, UV Sterilization Treatment and Transfer pumps**

Upon reaching STMicroelectronics, the RO water fills the RO tank up to a certain level and blanketed with nitrogen. The RO water is then pumped through a UV sterilizer treatment to remove remaining TOC. Below are the inventory inputs to SimaPro.



Documentation | Input/output | System description

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Low value	High value	Allocation %	Category	Comme
UV sterilizing treatment	1	p	Amount	0	0	100 %	Others	

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Low value	High value	Comment

Inputs

Known inputs from nature (resources)

Name	Amount	Unit	Low value	High value	Comment
water (process)	321260	kg	0	0	RO water from Pnuemonix
nitrogen	1461.6	kg	0	0	Blanketing N2 for RO and UPW tanks
silicon (in SiO2)	69.12	kg	0	0	quartz glass sleeve
recycling glass	17.28	kg	0	0	quartz glass sleeve

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Low value	High value	Comment
UV lamp	259.2	kg	0	0	

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Low value	High value	Comment
Electricity from gas B250	1460037	kWh	0	0	Electricity consumption for UV and transfer pumps

Figure 4.10: Simapro inventory inputs for UV sterilization treatment

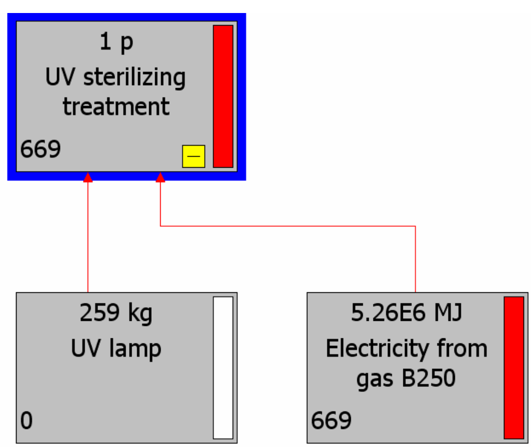


Figure 4.11: SimaPro tree for UV sterilization treatment

Step 4: **Membrane Degasifier and Vacuum pumps**

After passing through the UV sterilization process, the treated water is further treated by removing CO2 and O2 from the water by membrane degasifier. Vacuum pumps are used to remove the dissolved gases to the exhaust. Chilled water is used in heat exchanger to remove excess heat from the gases and condensate it into liquid. Below are the inventory inputs to SImaPro.

Documentation | Input/output | System description

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Low value	High value	Allocation %	Category
Membrane degasifier	1	p	Amount	0	0	100 %	Others

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Low value	High value	Comment

Inputs

Known inputs from nature (resources)

Name	Amount	Unit	Low value	High value	Comment
water (process)	321260	kg	0	0	Water after UV treatment
nitrogen	5846.4	kg	0	0	Sweeping N2

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Low value	High value	Comment
PP A	126	kg	0	0	polypropylene fibers for membrane
PVDF	54	kg	0	0	membrane cartridge
stainless steel	180	kg	0	0	casing
EN-GJL-250	100	kg	0	0	vacuum pump and motor
X6CrNiMoTi17-12-2	20	kg	0	0	vacuum pump
GX4CrNiMo19-11	50	kg	0	0	vacuum pump and motor
Copper wire	30	kg	0	0	vacuum motor

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Low value	High value	Comment
Electricity from gas B250	973358	kWh	0	0	electricity consumption for vacuum pump

Figure 4.12: SimaPro inventory inputs for membrane degasifier

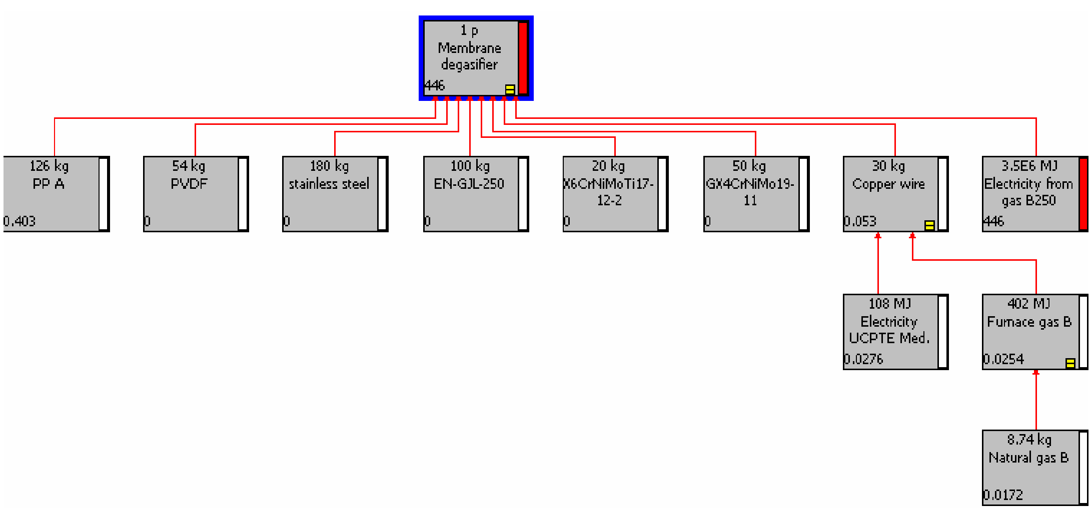
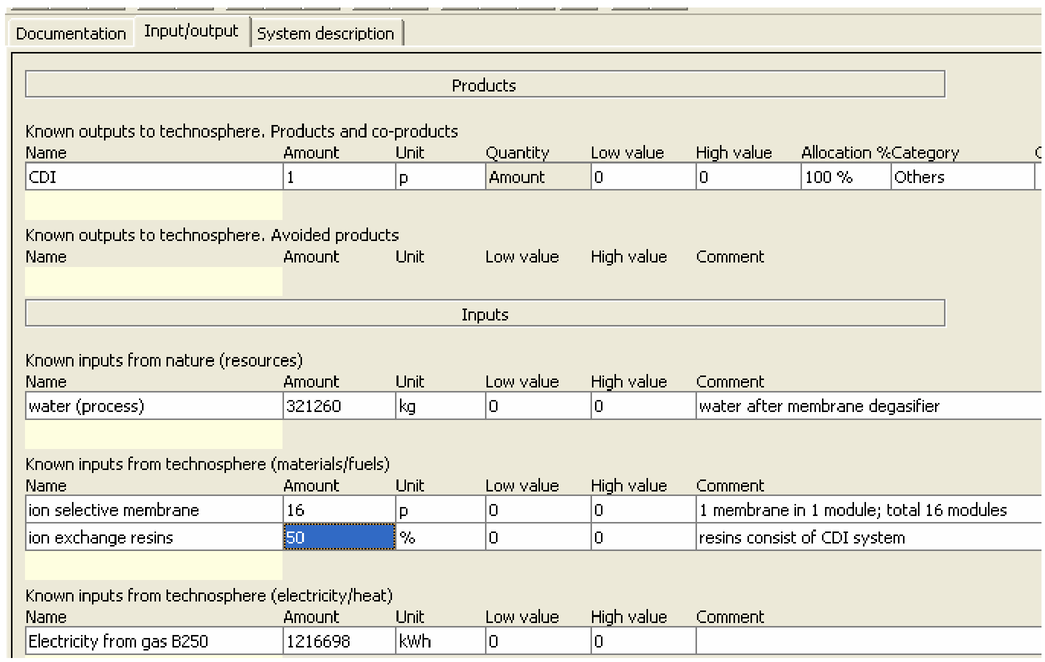


Figure 4.13: SimaPro tree for membrane degasifier

Step 5: **Continuous De-Ionizer**

After removing the unwanted gas in the water, the next step is to remove TDS and silica in the water by separating the ions. The CDI unit is made of 8 modules with a membrane to separate the product and reject water. There are also ion exchange resins in each module. Below are the inventory inputs to SimaPro.


Documentation | Input/output | System description

Products

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Low value	High value	Allocation %	Category
CDI	1	p	Amount	0	0	100 %	Others

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Low value	High value	Comment

Inputs

Known inputs from nature (resources)

Name	Amount	Unit	Low value	High value	Comment
water (process)	321260	kg	0	0	water after membrane degasifier

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Low value	High value	Comment
ion selective membrane	16	p	0	0	1 membrane in 1 module; total 16 modules
ion exchange resins	50	%	0	0	resins consist of CDI system

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Low value	High value	Comment
Electricity from gas B250	1216698	kWh	0	0	

Figure 4.14: SimaPro inventory inputs for Continuos Deionizer

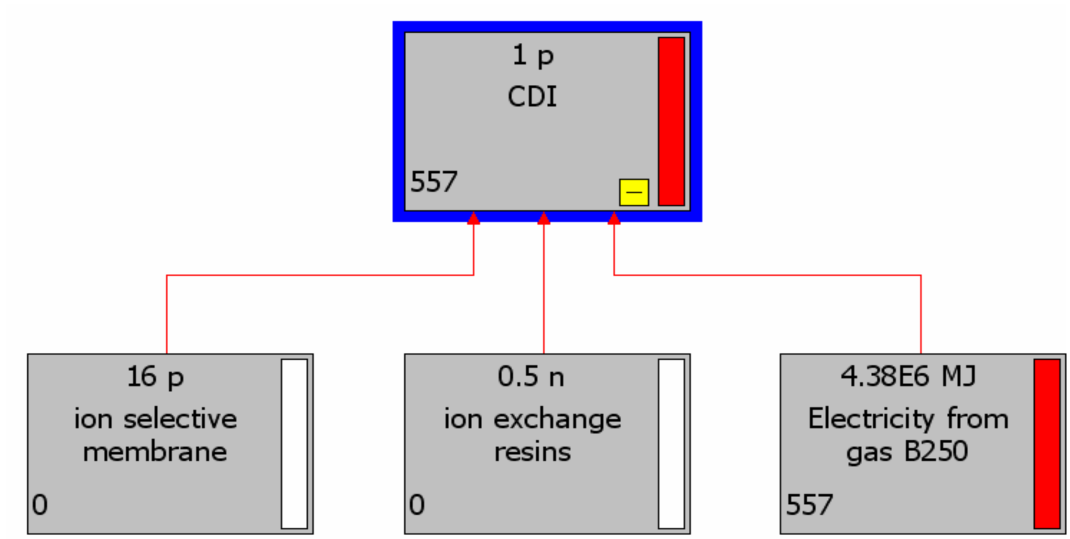


Figure 4.15: SimaPro tree for CDI

Step 6: **Mixed Bed, Booster pump and Ultrafiltartion**

To further remove TDS and silica, the treated water is passed through a resin mixed bed before going through the final filter. There are 2 mixed bed tanks made of PVDF material coated with FRP. The resins are normally ½ filled. Booster pumps are used to make sure the pressure in the line to the end user remain constant. The pump specification is the same as the transfer pumps. The last filtration is to filter particle size 0.2 and 0.04 micron. The membrane is made of polymer material.

Documentation | Input/output | System description

Known outputs to technosphere. Products and co-products

Name	Amount	Unit	Quantity	Low value	High value	Allocation %	Category
Mixed Bed, booster and uf	1	p	Amount	0	0	100 %	Others

Known outputs to technosphere. Avoided products

Name	Amount	Unit	Low value	High value	Comment

Inputs

Known inputs from nature (resources)

Name	Amount	Unit	Low value	High value	Comment
water (process)	321260	kg	0	0	

Known inputs from technosphere (materials/fuels)

Name	Amount	Unit	Low value	High value	Comment
mixed bed resins	50	%	0	0	amount of mixed bed resins in each tank
EN-GJL-250	174	kg	0	0	booster pump and motor
X6CrNiMoTi17-12-2	37	kg	0	0	booster pump
GX4CrNiMo19-11	87	kg	0	0	booster pump and motor
Copper wire	50	kg	0	0	booster motor
polysulfone	100	%	0	0	UF membrane and housing

Known inputs from technosphere (electricity/heat)

Name	Amount	Unit	Low value	High value	Comment
Electricity from gas B250	1216698	kWh	0	0	electricity consumption for booster pumps

Figure 4.16: SimaPro inventory inputs for mixed bed, booster and ultra-filtration

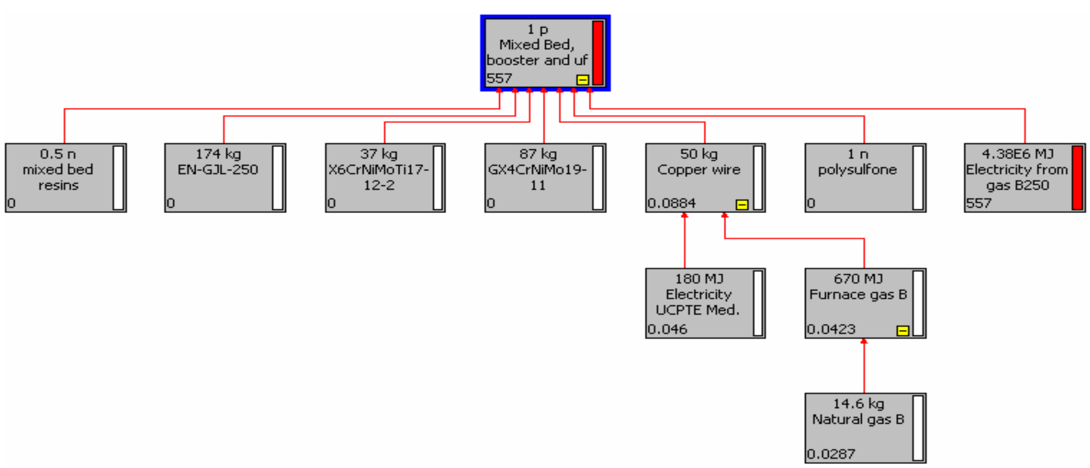


Figure 4.17: SimaPro tree for mixed bed, booster and UF

Step 7: **Manufacture of UPW**

The manufacturing of UPW started at Numonyx where raw water is passes through RO process. The RO water is transferred to STMicroelectronics UPW plant to do the rest of the treatment of water such as UV sterilization, membrane degasification, continuous deionizer and final filtration. Below are the product flow and the process.

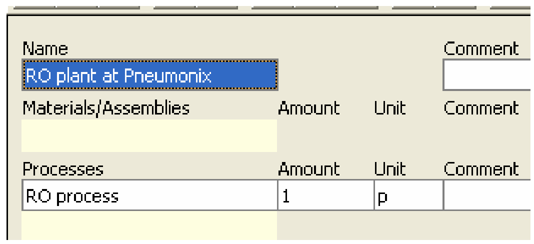


Figure 4.18: SimaPro inventory input for RO plant at Numonyx

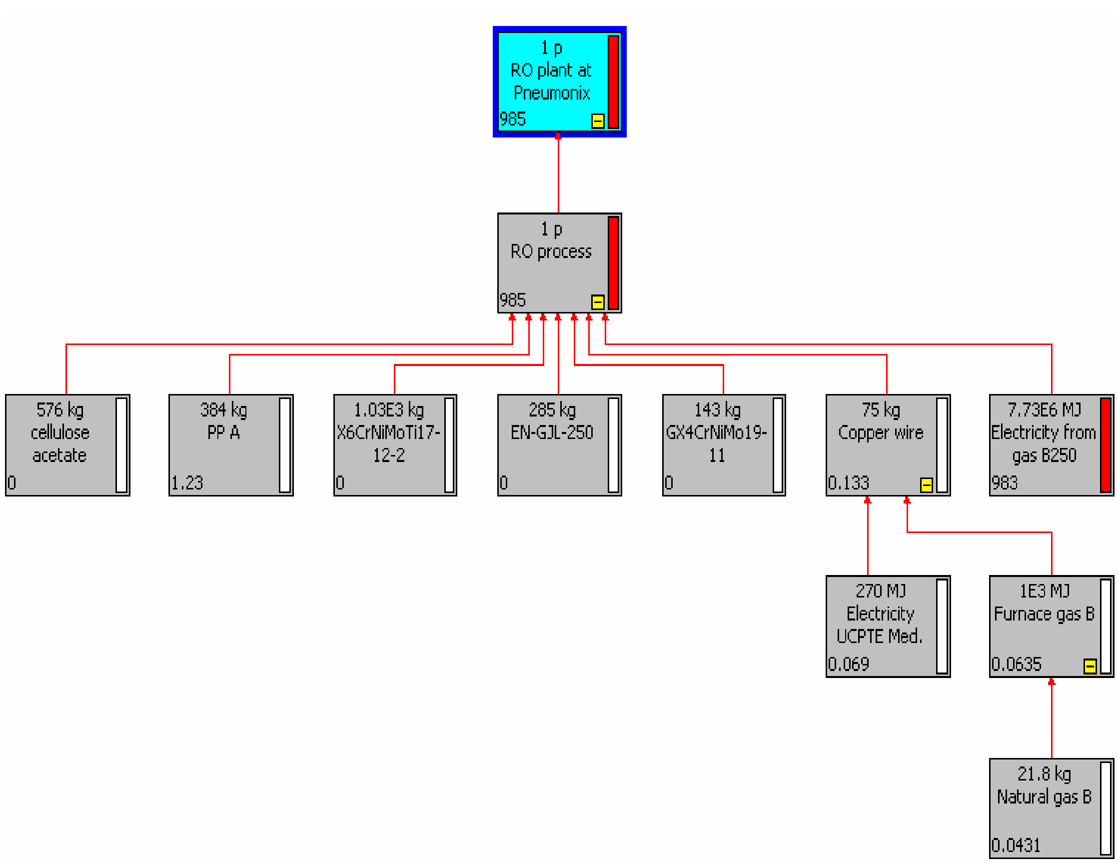
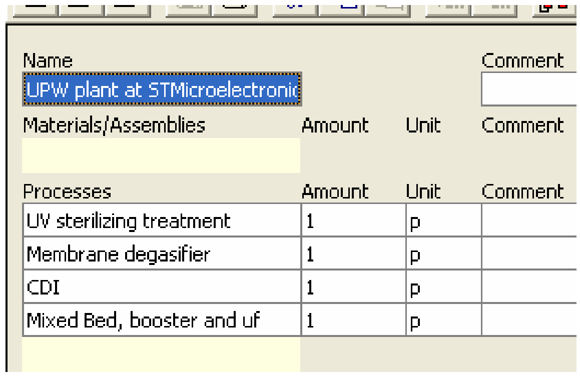


Figure 4.19: SImaPro tree for RO plant at Numonyx



Name: UPW plant at STMicroelectronic

Materials/Assemblies	Amount	Unit	Comment

Processes	Amount	Unit	Comment
UV sterilizing treatment	1	p	
Membrane degasifier	1	p	
CDI	1	p	
Mixed Bed, booster and uf	1	p	

Figure 4.20: SimaPro inventory input for UPW plant at STMicorlectronic

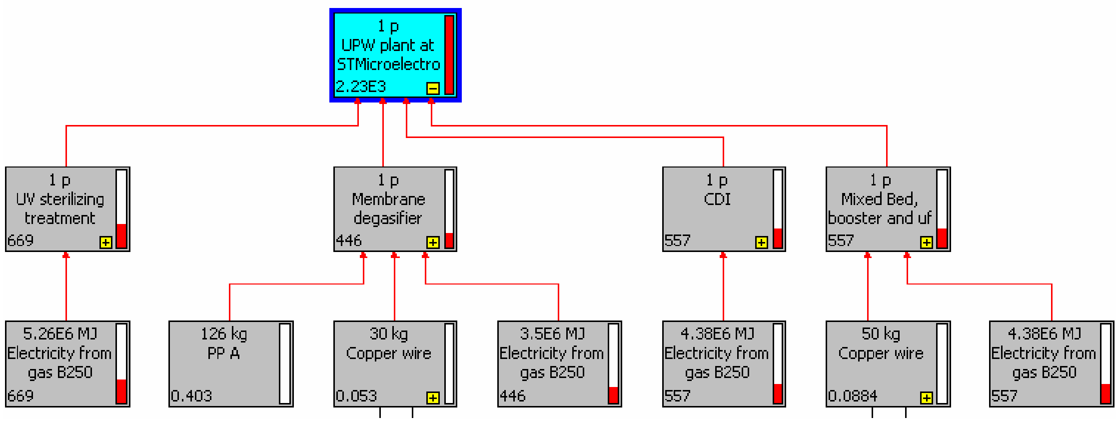
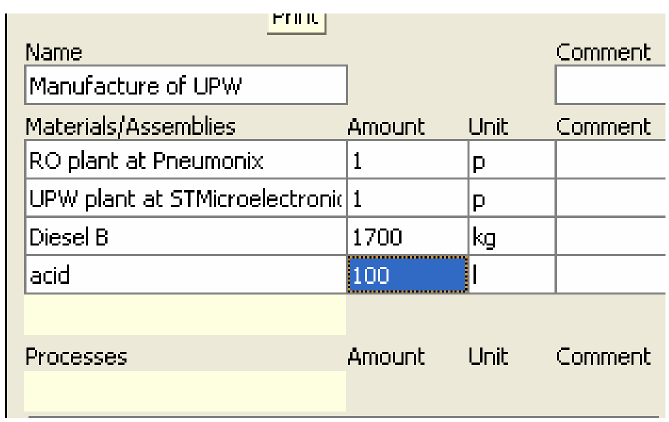


Figure 4.21: SimaPro tree for UPW plant at STMicroelectronics



Name: Manufacture of UPW

Materials/Assemblies	Amount	Unit	Comment
RO plant at Pneumonix	1	p	
UPW plant at STMicroelectronic	1	p	
Diesel B	1700	kg	
acid	100	l	

Processes	Amount	Unit	Comment

Figure4.22: SimaPro inventory inputs for manufacturing of UPW

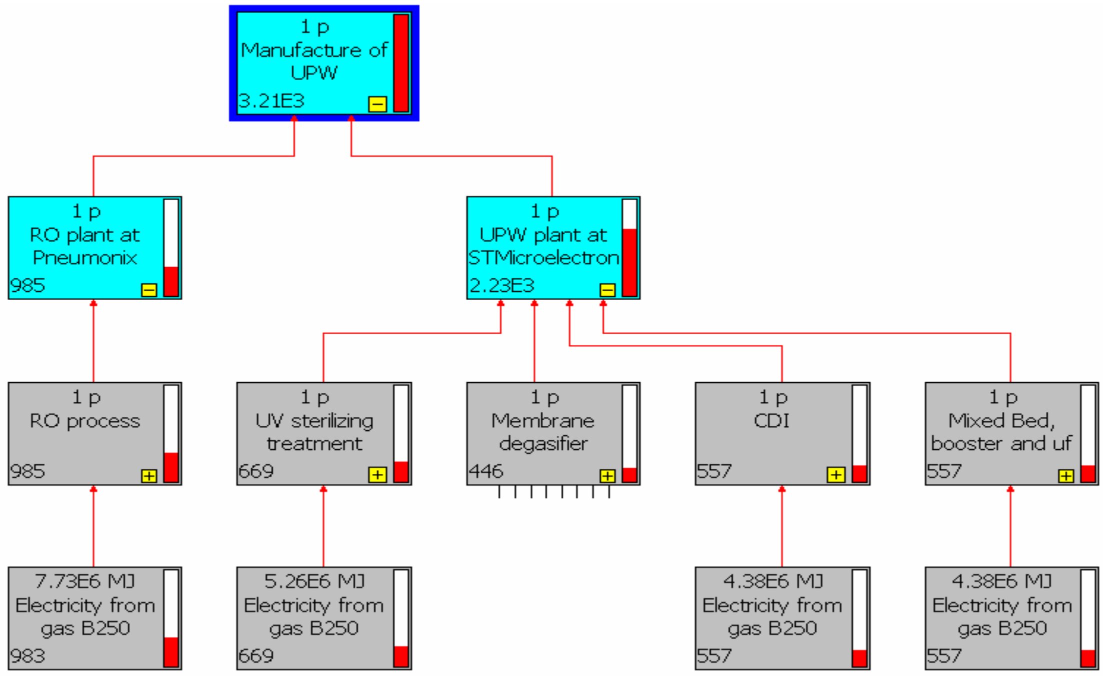


Figure4.23: SimaPro tree for manufacturing of UPW

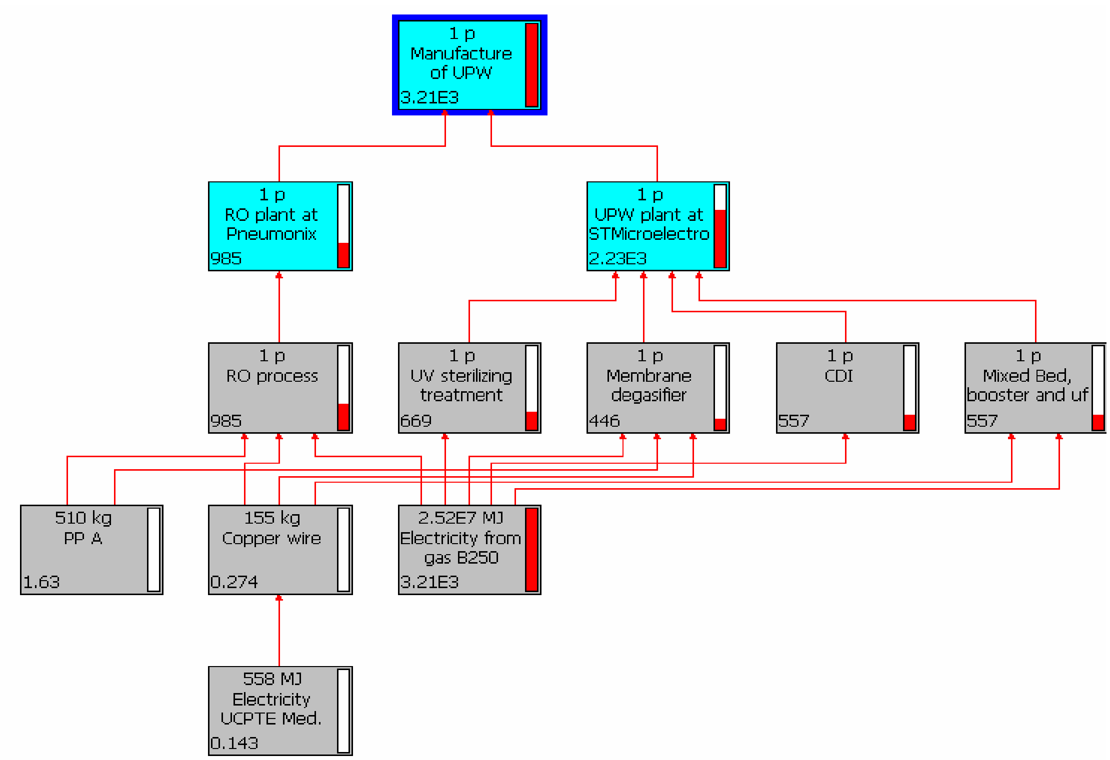


Figure 4.24: SimaPro network for manufacturing of UPW

CHAPTER 5

Life Cycle Impact Assessment

5.1 Introduction

In LCIA, the materials and processes involved will be analyzed by SimaPro and the results will be shown according to single score, normalization and damage assessment. The impact assessment method chosen, Eco Indicator 99, however normalizes the impact results with the environmental effects caused by an average European during a year. Since UPW is manufactured mainly from water, the process involved in the production would be compared instead.

The impact potentials are calculated according to the LCI results. Impact assessment methods hold data on:

1. Characterisation
2. Damage assessment
3. Normalization
4. Weighting
5. Single score

5.1.1 Characterization

This is the first result display at LCIA. This factor reflects to the relative contribution of an LCI result to impact category indicator result.

5.1.2 Damage Assessment

Damage assessment shows the damage to human health, ecosystem quality and resources. Some impact assessment method allow for adding impact category indicators that have a single unit.

5.1.3 Normalization

Normalization provides a basic for comparing different types of environmental impact categories (all impacts get the same unit).

5.1.4 Weighting

Weighting implies assigning a weighting factor to each impact category depending on the relative importance.

5.1.5 Single Score

Single scored is the total impact of each process of product being analysed and compared to human health, ecosystem quality and resources.

5.2 LCIA result 1-Compare RO and UPW plant

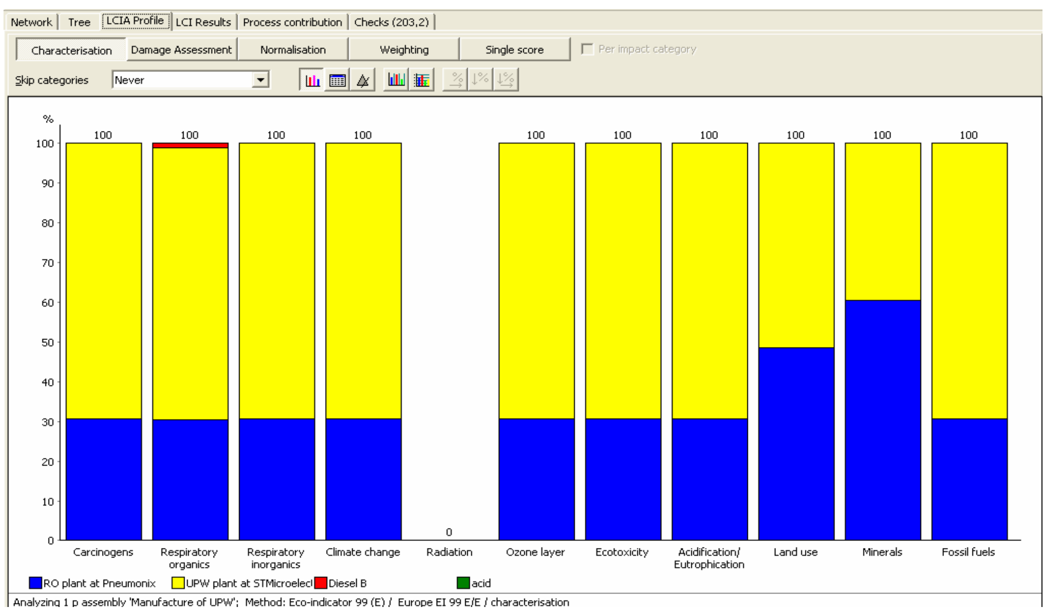


Fig 5.1: Characterizations output for RO and UPW plant

Characterization

Fig 5.1 shows the characterization result of RO process and UPW process. Radiation is not affected by all the process. The result shows that the highest contribution to the impact categories comes from UPW process due to the different processes in manufacturing ultra pure water as compared to manufacturing RO water only.

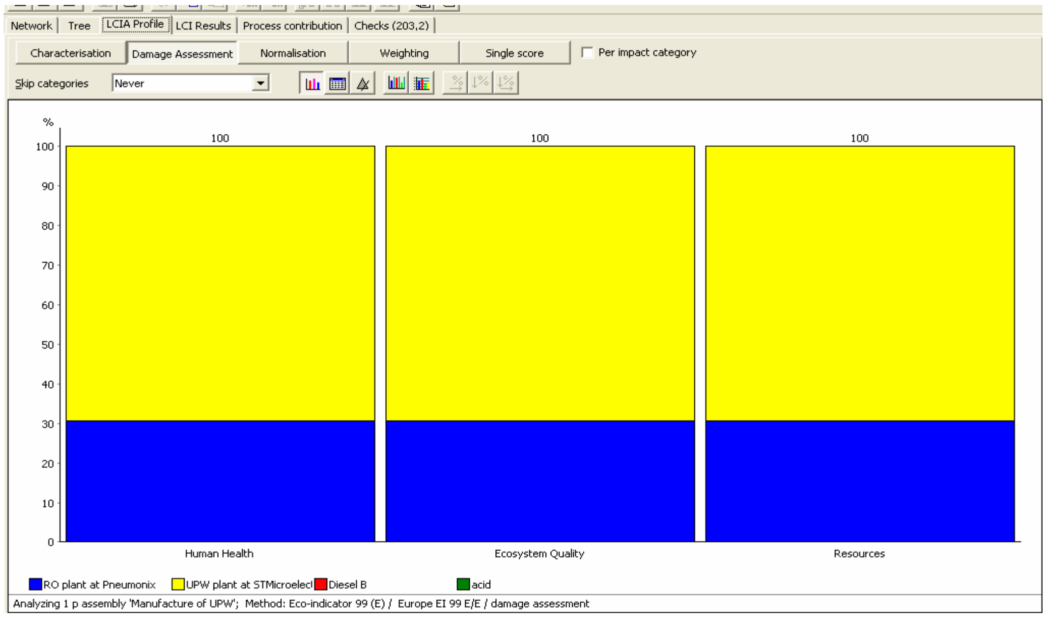


Fig 5.2: Damage assessment output for RO and UPW plants

Damage Assessment

Fig 5.2 shows the damage assessment results for the RO and UPW processes at Numonyx and STMicroelectronic Pte Ltd. The damage caused by UPW process is more compared to RO process.

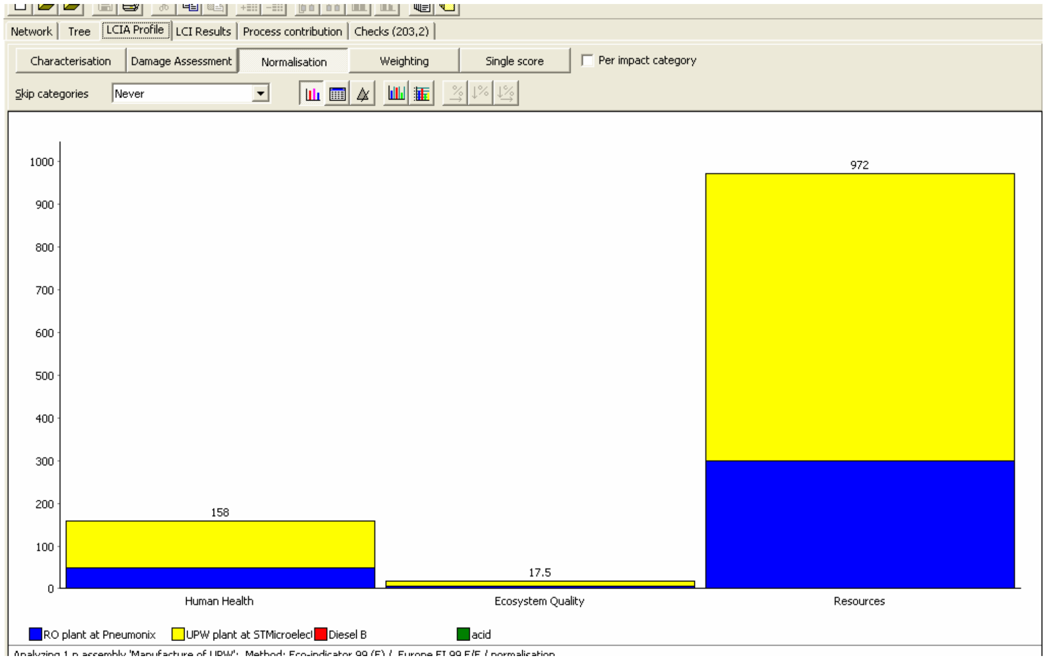


Fig 5.3: Normalization output for RO and UPW plant.

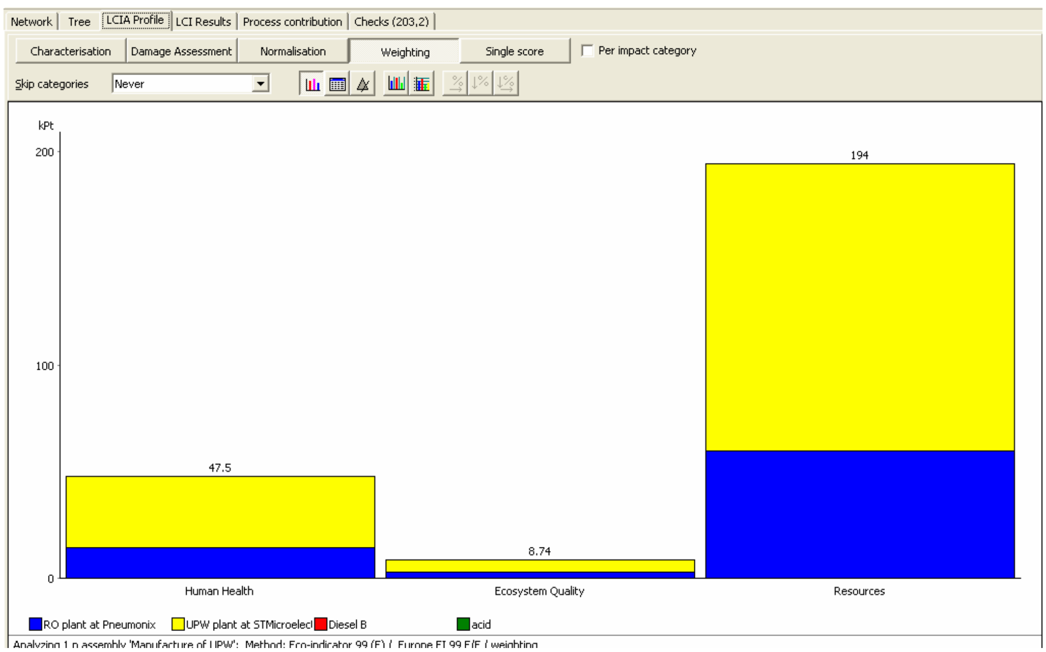


Fig 5.4: Weighting output for RO and UPW plant

Normalization and weighting

Fig 5.3 and Fig 5.4 shows the same results for the 4 processes. The results show that the resources are severely affected by these processes.

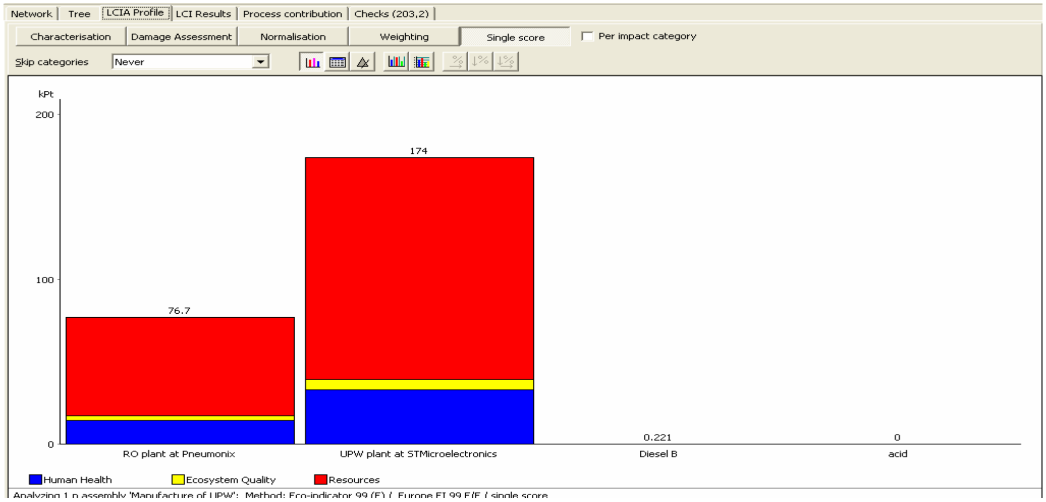


Fig 5.5: Single score output for RO and UPW plants

Single Score

Fig 5.5 shows the results for single score output for RO and UPW processes. UPW process at STMicroelectronics has the highest impact to human health, ecosystem quality and resources compared to RO process at Numonyx. The diesel and acid used in the production of UPW is too small to be shown in the graph.

5.3 LCIA result 2 – Manufacturing process of UPW

5.3.1 Process 1- RO process in Numonyx

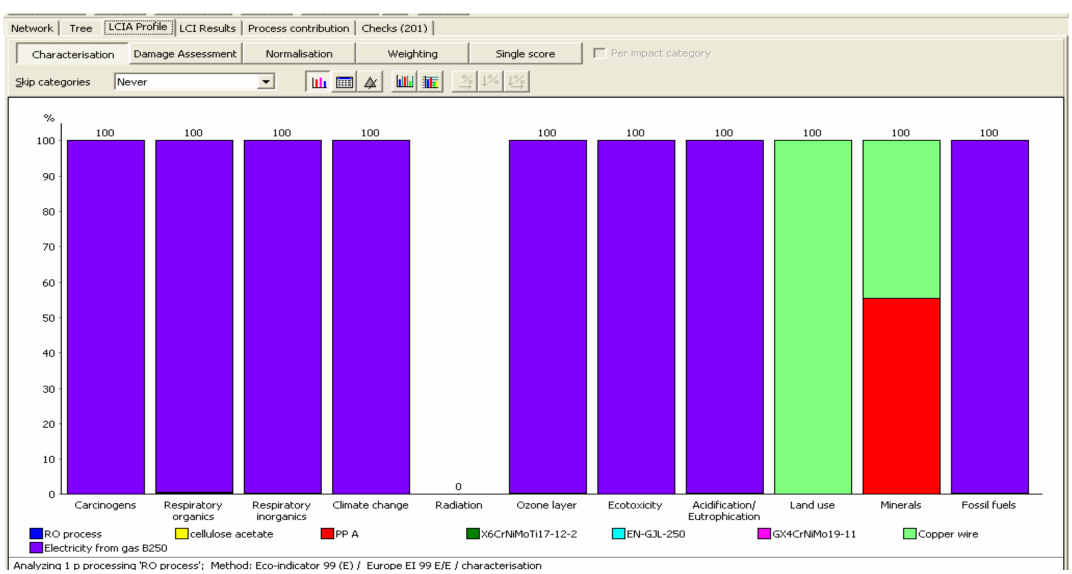


Fig 5.6: Characterisation output for RO process at Numonyx Pte Ltd

Characterization

Fig 5.6 shows the result for characterization output for RO process at Numonyx Pte Ltd. The result shows that only radiation is not affected by RO process.

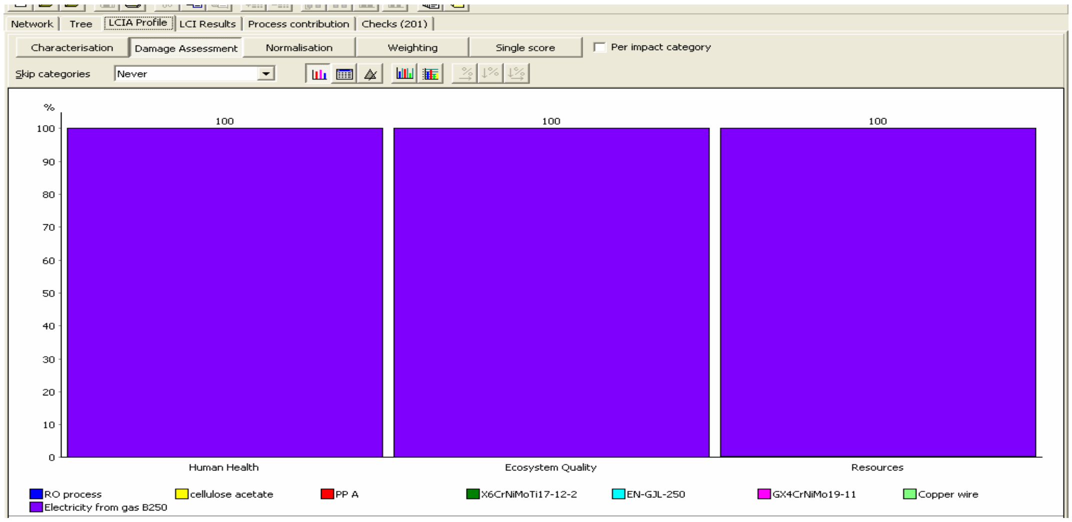


Fig 5.7: Damage assessment output for RO process at Numonyx

Damage Assessment

Fig 5.7 shows the damage assessment output for RO process at Numonyx Pte Ltd. The result shows that RO process affects human health, ecosystem quality and resources severely.

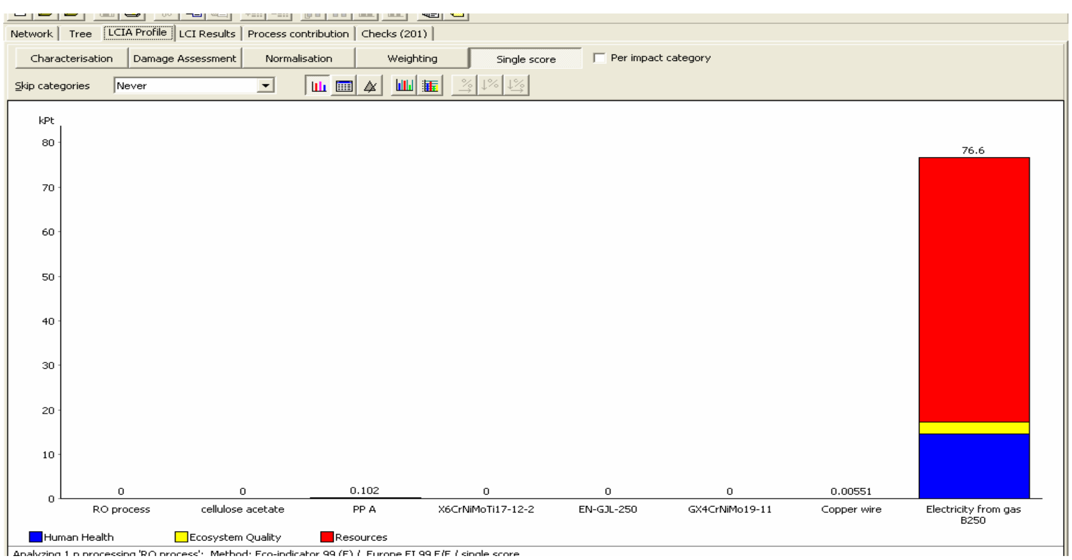


Fig 5.8: Single Score output for RO process at Numonyx

Single Score

Fig 5.8 shows the single score output for RO process at Numonyx. The result shows that electricity that comes from the RO pumps is the only cause of effects to human health, ecosystem quality and resources.

5.3.2 Process 2- UV sterilizing treatment

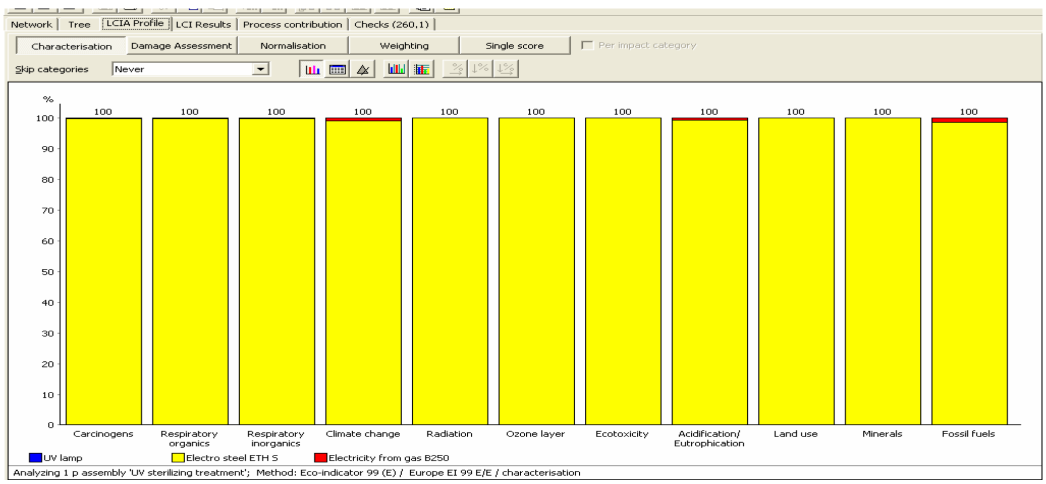


Fig 5.9: Characterization output for UV sterilizing treatment

Characterization

Fig 5.9 shows the characterization result for UV sterilizing treatment process at STMicroelectronics Pte Ltd. The result shows that the UV sterilizers which are made up of stainless steel parts and housing have a severe impact to all the impact categories.

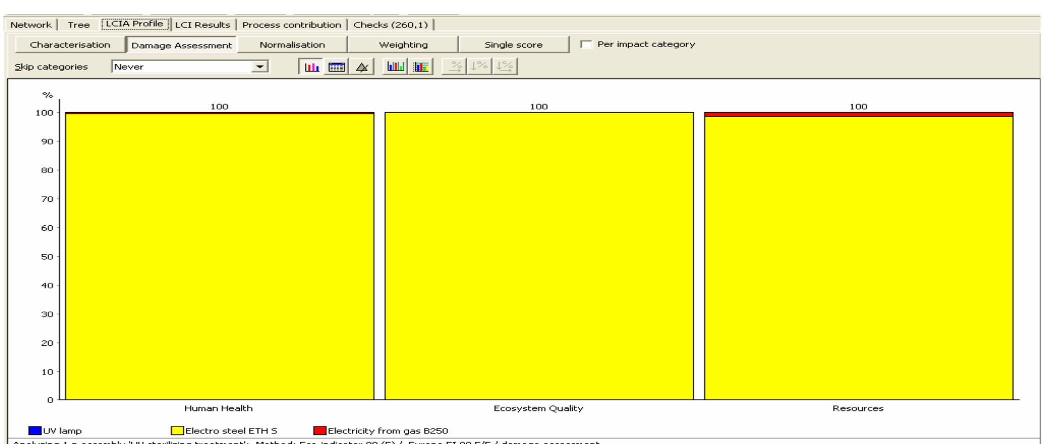


Fig 5.10: Damage assessment output for UV sterilizing treatment

Damage assessment

Fig 5.10 shows the damage assessment result for UV sterilizing treatment process at STMicroelectronics Pte Ltd. The result shows that UV sterilizer product affects human health, ecosystem quality and resources severely especially stainless steel.

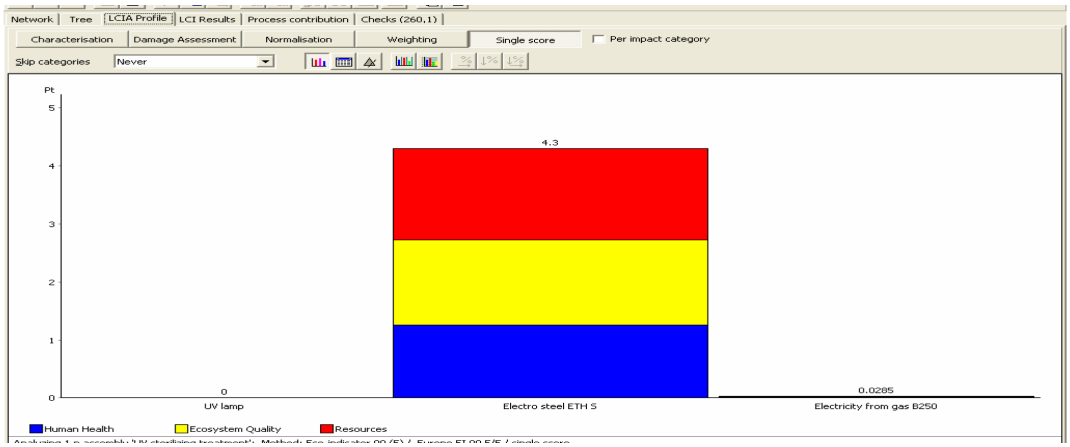


Fig 5.11: Single score output for UV treatment process

Single Score

Fig 5.11 shows the single score output for UV sterilizing treatment process. The result shows that only the stainless steel materials used to make the machines have an equal effect to human health, ecosystem quality and resources.

5.3.3 Process 3- Membrane Degasifier

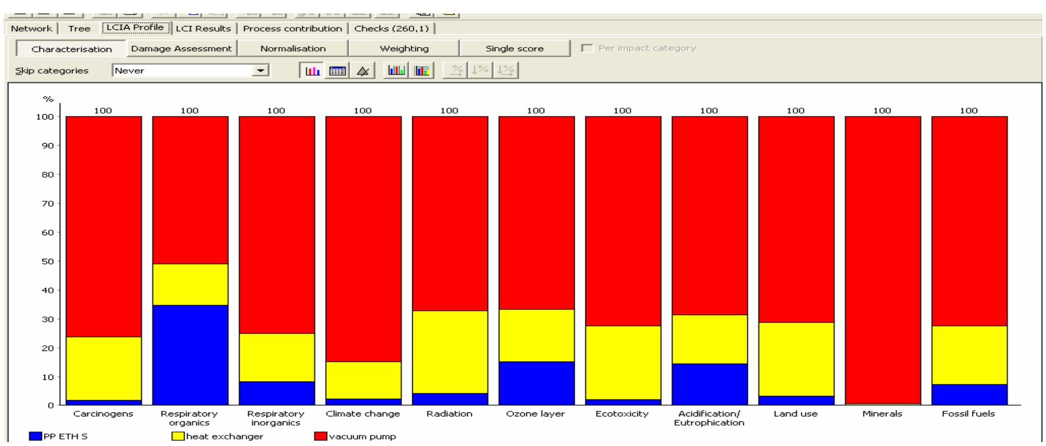


Fig 5.12: Characterization output for membrane degasifier process

Characterization

Fig 5.12 shows the characterization result for membrane degasifier process which includes heat exchanger and vacuum pumps. The result shows that vacuum pumps have the highest effect on the impact indicators followed by heat exchanger and membrane degasifier which is mainly made of plastic material.

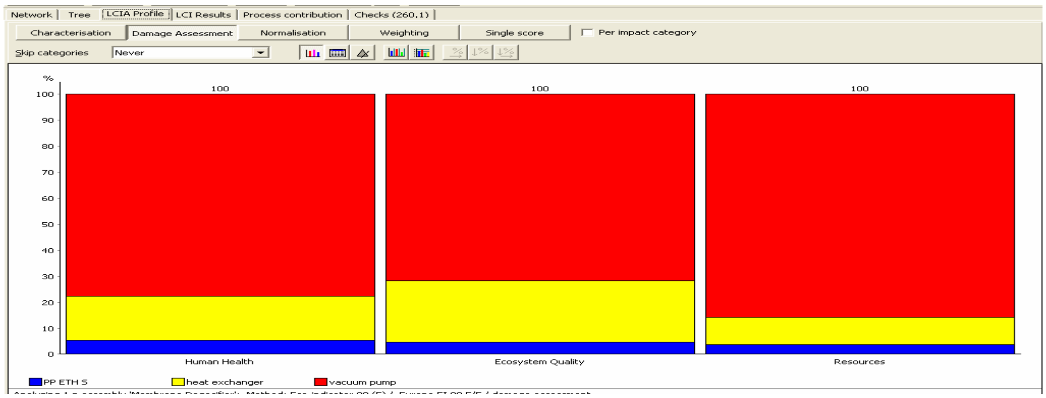


Fig 5.13: Damage assessment output for membrane degasifier process

Damage Assessment

Fig 5.13 shows the damage caused to human health, ecosystem quality and resources by membrane degasifier process. Vacuum pump caused the most damage among the rest due to electricity usage by the pump and materials used to manufacture one. Heat exchanger uses process chilled water to reduce the temperature of the gas and membrane is mainly made up of plastic.

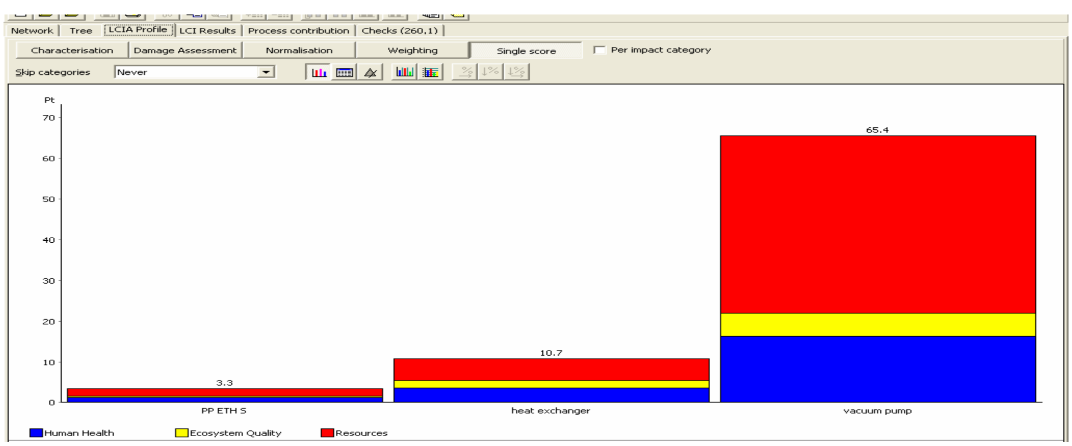


Fig 5.14: Single score output for membrane degasifier process

Single Score

Fig 5.14 shows the single score output for membrane degasifier process. The result shows that vacuum pump have the highest effect to human health, ecosystem quality and resources compared to heat exchanger material and PP plastic.

5.3.4 Process 4 – Continuous De-ionizer

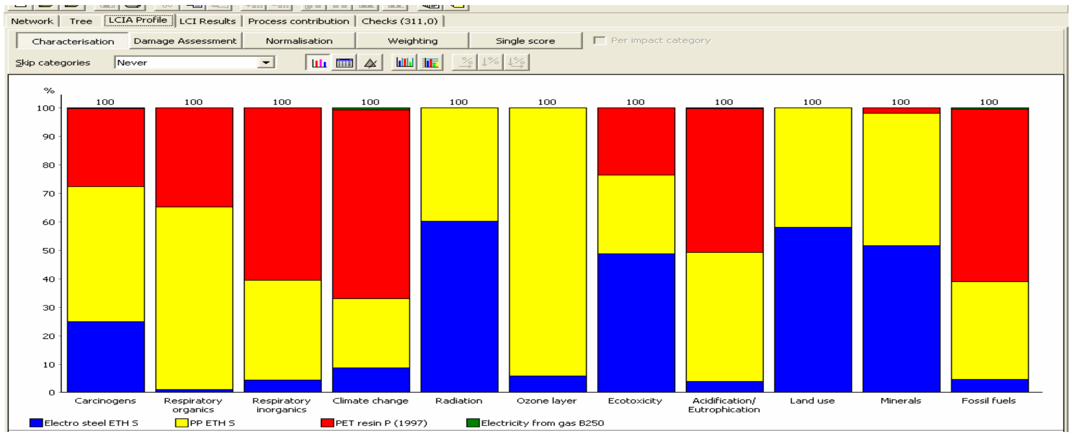


Fig 5.15: Characterization output of CDI process

Characterization

Fig 5.15 shows the characterization output for CDI process. The result shows that the stainless frame and housing of the CDI have a severe effect on radiation, ecotoxicity, landuse and minerals. The result also shows the highest contribution to ozone layer depletion is caused by the PP material used for making membrane.

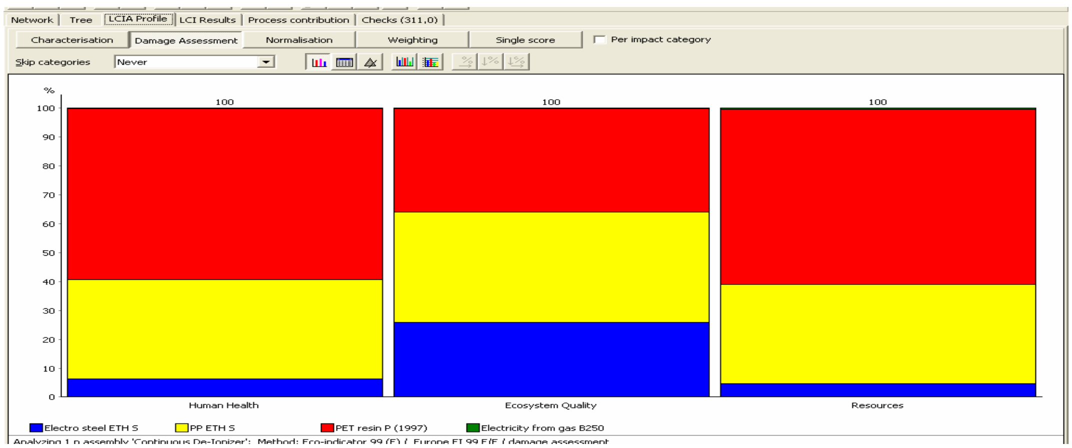


Fig 5.16: Damage Assessment output for CDI process

Damage Assessment

Fig 5.16 shows the damage assessment output for CDI process. The result shows that stainless steel production has the highest effect to ecosystem quality. The PET resin has the same severe effect to human health and resources. The PP material used to make the membrane have the same effect to human health, ecosystem quality and resources.

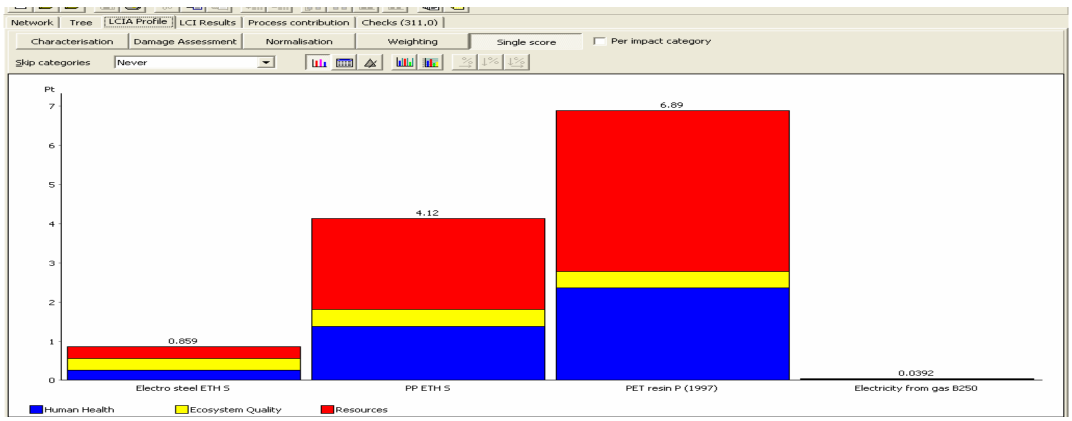


Fig 5.17: Single score output for CDI process

Single Score

Fig 5.17 shows the single score output for CDI process. The result shows that PET resin have the highest effect to human health and resources but have the same effect for ecosystem quality with stainless steel and PP plastic.

5.3.5 Process 5 – Mixed Bed, Booster pump and UF

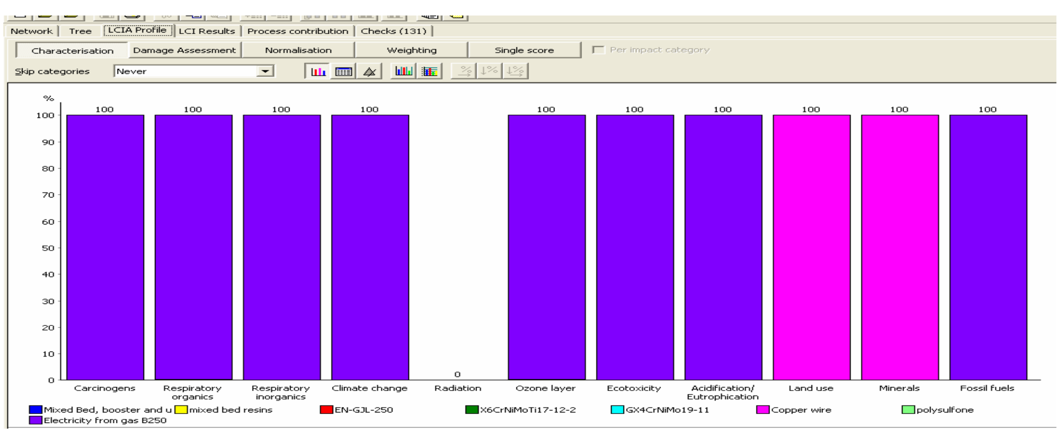


Fig 5.18: Characteristic output for Mixed bed, booster pump and UF process

Characterization

Fig 5.18 shows the characterization output for mixed bed, booster pump and UF process. The result shows that only radiation is not affected by this process. The result also shows that copper wire affects the land use and minerals on earth whereas electricity has a severe impact on other impact category.

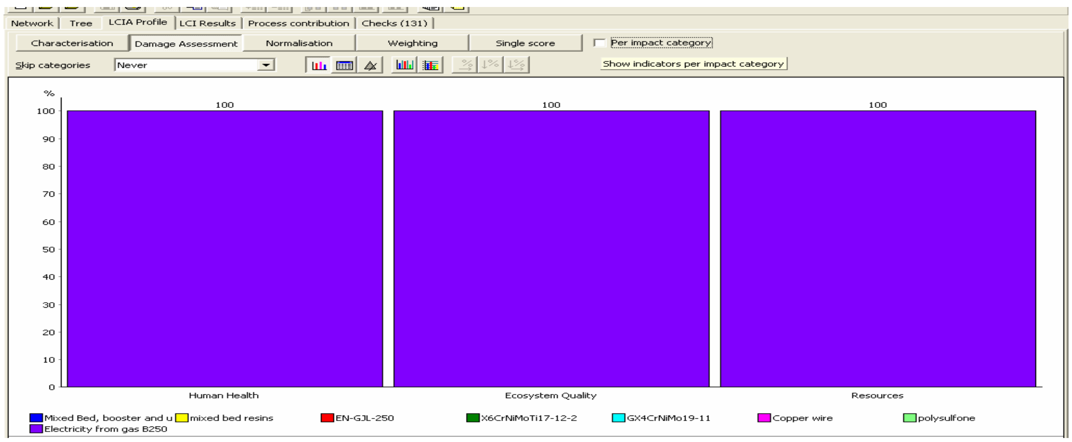


Fig 5.19: Damage assessment output for mixed bed, booster pump and UF process.

Damage Assessment

Fig 5.19 shows the damage assessment output for mixed bed, booster pump and UF process. The result shows that electricity used by the booster pump severely affects the human health, ecosystem quality and resources.

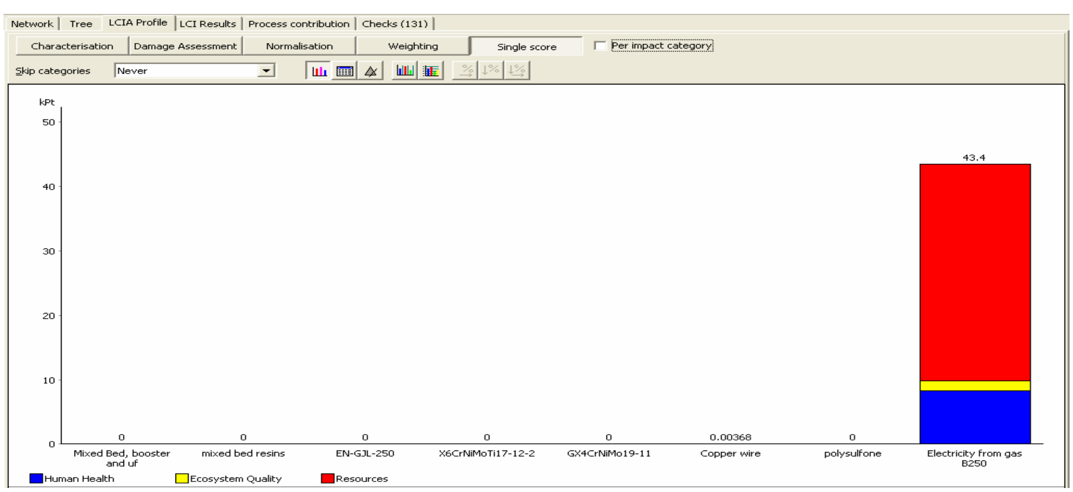


Fig 5.20: Single score output for mixed bed, booster pump and UF process

Single Score

Fig 5.20 shows the single score output for mixed bed, booster pump and UF process. The result shows that only electricity has the highest effect on resources followed by human health and ecosystem quality.

CHAPTER 6

Life Cycle Interpretation

6.1 Introduction

Life cycle interpretation is defined as "a systematic procedure to identify, qualify, check and evaluate information from the results of the LCI and/or LCIA of a product system, and present them in order to meet the requirements of the application as described in the goal and scope of the study. Also, Life Cycle Interpretation includes communication to give credibility to the results of other LCA phases (namely the LCI and LCIA) in a form that is both comprehensive and useful to the decision maker" in ISO 14043. Therefore the aim is to check the results of the inventory analysis and impact assessment against the goal and scope defined in the study.

6.2 Methodology

The last phase in the LCA methodology is the interpretation of the study. In this phase, the following steps need to be conducted:

1. Identify the most important results of the Inventory Analysis and of the Impact Assessment.

2. Evaluate the outcome of the study by following these routines: completeness check, sensitivity analysis, uncertainty analysis and consistency check.

3. Conclusions, recommendations and reporting, including a definition of the final outcome such as:

    - A comparison with the original goal of the study
    - The drawing up of recommendations
    - Final reporting of the results

The results of the Interpretation may lead to a new iteration round of the study, including a possible adjustment of the original goal.(Jacqueline Aloisi Larderel, 2003)

6.2.1 Identify significant issues

“Significant issues” are data elements that contribute significantly to the outcome of the results of both LCI and LCIA for each product. Examples of “significant issues” include inventory parameters (raw material, chemical, energy, etc), the impact indicators used (waste, emissions, acidification, etc) and life cycle stages essentials (generation of energy, delivery, etc). Due to the complexities involved in an LCA study, the significant issues are identified mainly based on the impact assessment scores. Thus the process or products having the greatest effect on the impact assessment results are identified for further analysis.

The next recommended approaches are:

- Contribution Analysis – comparison between the magnitudes of environmental impacts associated with life cycle stages or groups of process to the total impacts associated with the product of study.

- Dominance Analysis – identification of significant contributions using statistical tools or other methods such as qualitative or quantitative ratings.

- Anormaly Assessment – abnormal or surprising trend of results based from past history are evaluated and compared from studies conducted on similar product.

It is common in a LCA study that some inventory items although are quantitatively insignificant, but contributed significantly towards the final results. These data should be as detailed as possible. However those uncertainties data of large inventory items but contributed minimally to the environmental impacts may be ignored.

6.2.2 Evaluate the completeness, sensitivity and completeness of the Data

The second step of the LCI phase is the evaluation step to establish the correctness, validity and credibility of the results of the LCA. For this accomplishment, three tasks are required:

- Completeness check
- Consistency check
- Sensitivity check

Completeness check is to ensure that all relevant information and data needed for interpretation are available and complete. This should be done with the aid of a checklist, indicating for each process/product of study that the results are complete meeting the stated goal and scope of the LCA. Alternatively, an independent LCA expert may examine issues such as methodological approached, software modeling used, assumptions made, process flows and other relevant issues.

Consistency check ensures that the assumptions, data and methods used throughout the LCA process are in tandem with the goal and scope of the study. Differences in issues such as data quality indicators, data sources, etc had to be taken into consideration to achieve a highly accurate result.

Sensitivity check evaluates uncertainties and other expected deviations in identified "significant issues" so as to determine their sensitivity towards the final results of the LCA. They are performed by the following techniques for data quality analysis:

- Gravity analysis – identification of the data having the most contribution to the impact indicator results.

- Uncertainty analysis – LCA data variables are described to determine the significance of the impact indicator results.

- Sensitivity analysis – determines the effects of these variations on the impact indicator results of the study.

6.2.3 Conclusions and Recommendations

The final step in ISO 14043 is the interpretation stage which is to draw conclusions and make recommendations for the intended audience of the LCA study. The major results of the study should be discussed regarding its reliability and validity. Any errors, inconsistencies and incompleteness should be highlighted. At the end of this LCA, conclusions and recommendations are to be made so as to increase the confidence of the audience on the results of the study.

6.3 Inventory Analysis

6.3.1 Electricity Distribution

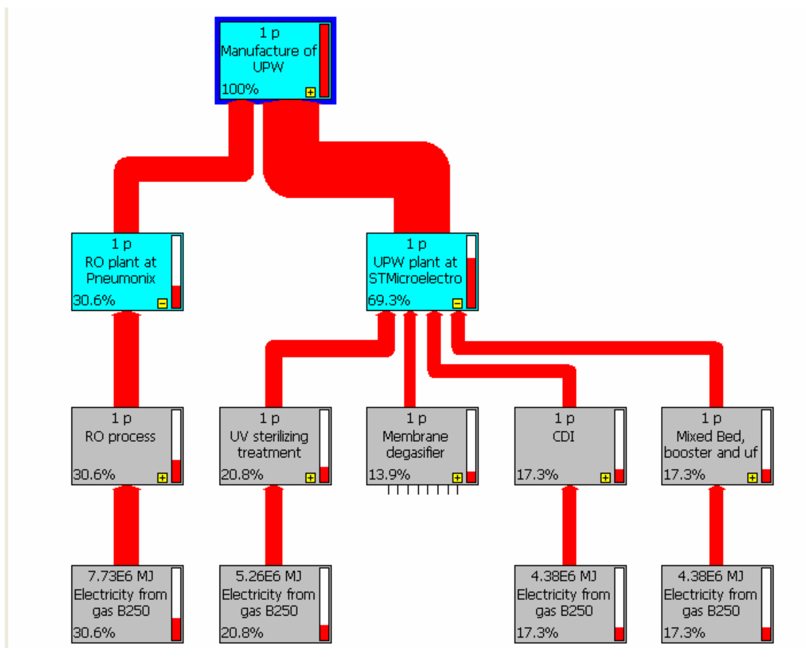


Fig 6.1: Tree's analysis output for electricity distribution of the overall manufacturing process

Name	Electrical Distribution (%)
RO process	30.6
UV sterilizing treatment	20.8
Membrane Degasifier	13.9
CDI	17.3
Mixed bed, booster and uf	17.3

Table 6.1: Electricity consumption for overall process

6.3.2 Damage to human health – RO plant

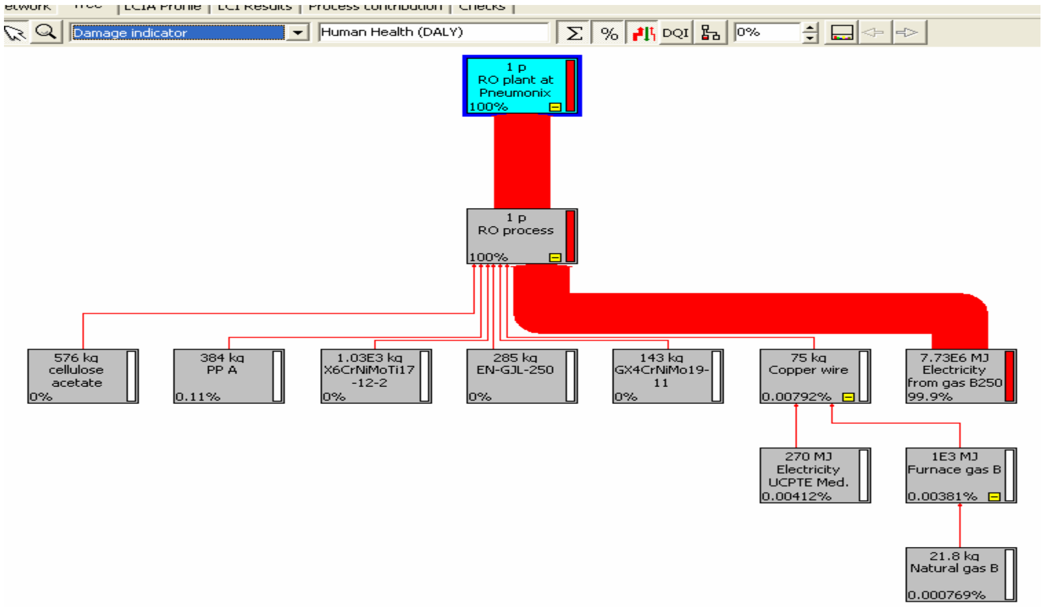


Fig 6.2: Tree's analysis output of RO plant at Numonyx to human health

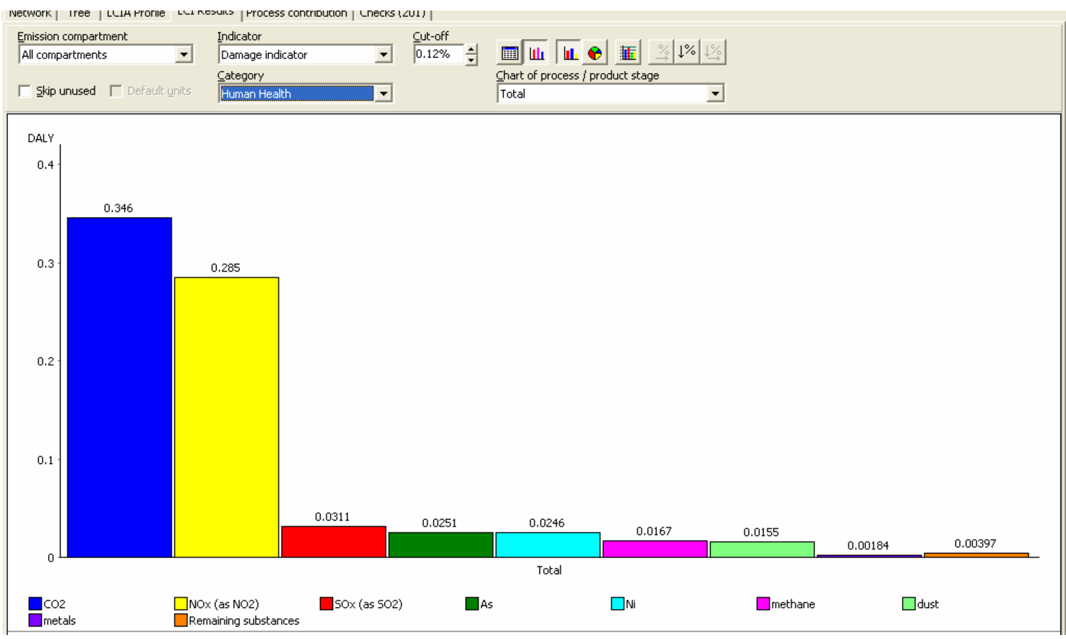


Fig 6.3: Damage indicator of RO plant at Numonyx to human health

Comments:

The major contributor for the human health in the RO plant at Numonyx Pte Ltd is the electricity consumption by the RO pumps with 99.9% as shown in Fig 6.2. Fig 6.3 shows that the CO2 and NOx caused the most damage to human health.

6.3.3 Damage to eco system – RO plant

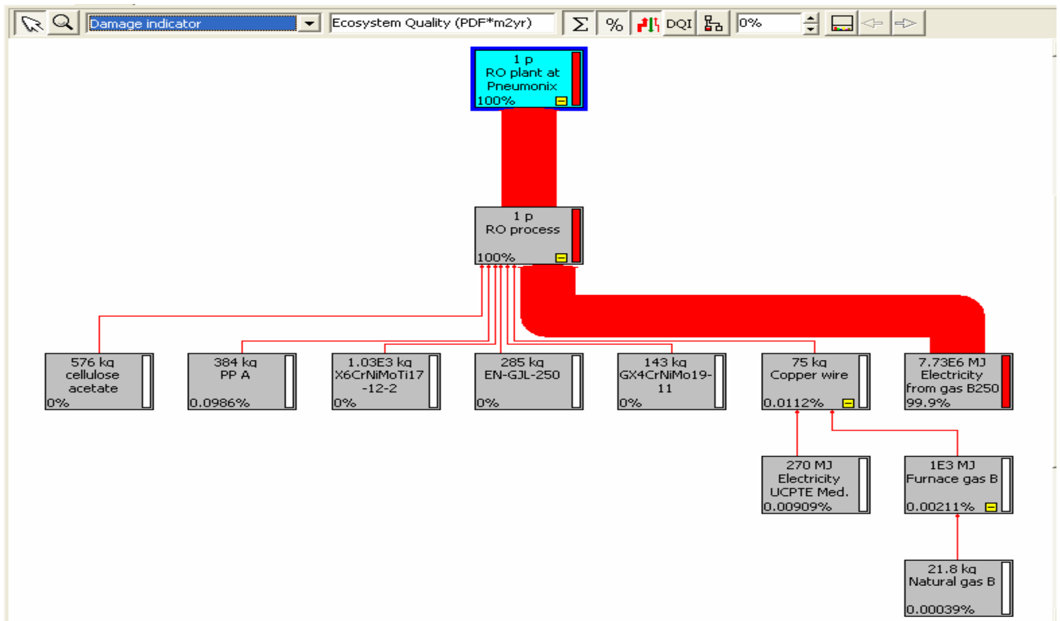


Fig 6.4: Tree's analysis output of RO plant at Numonyx to ecosystem quality

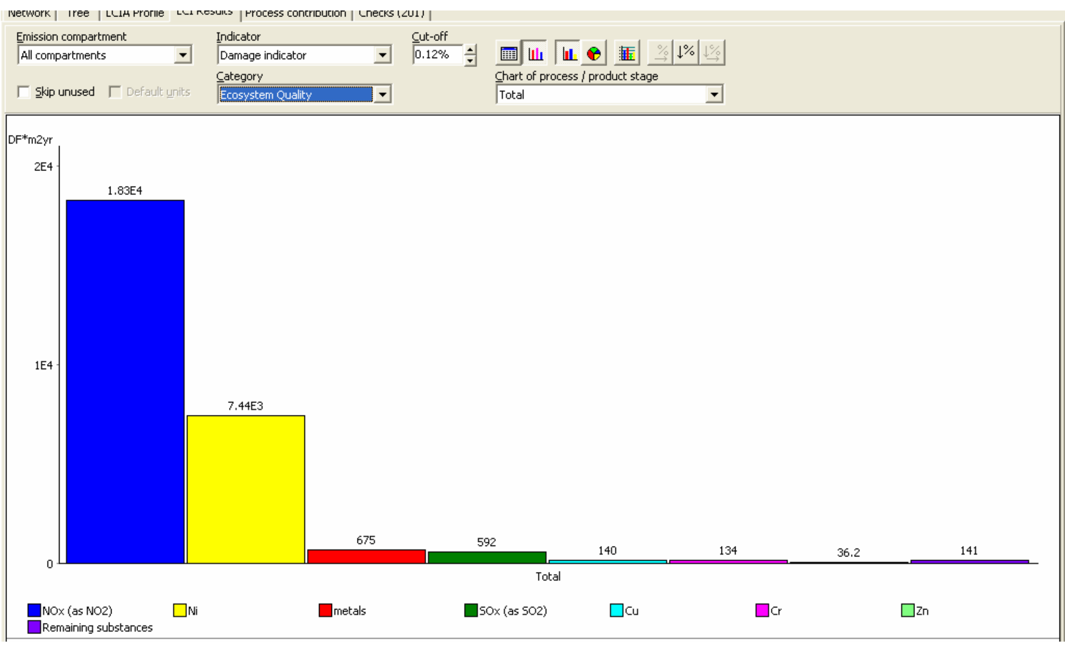


Fig 6.5: Damage indicator of RO plant at Numonyx to ecosystem quality

Comments:

The use of energy (99.9%) by RO pumps is the only major contributor for the damage to ecosystem quality. Damage to ecosystem is caused by NOx and Nickel.

6.3.4 Damage to resources – RO plant

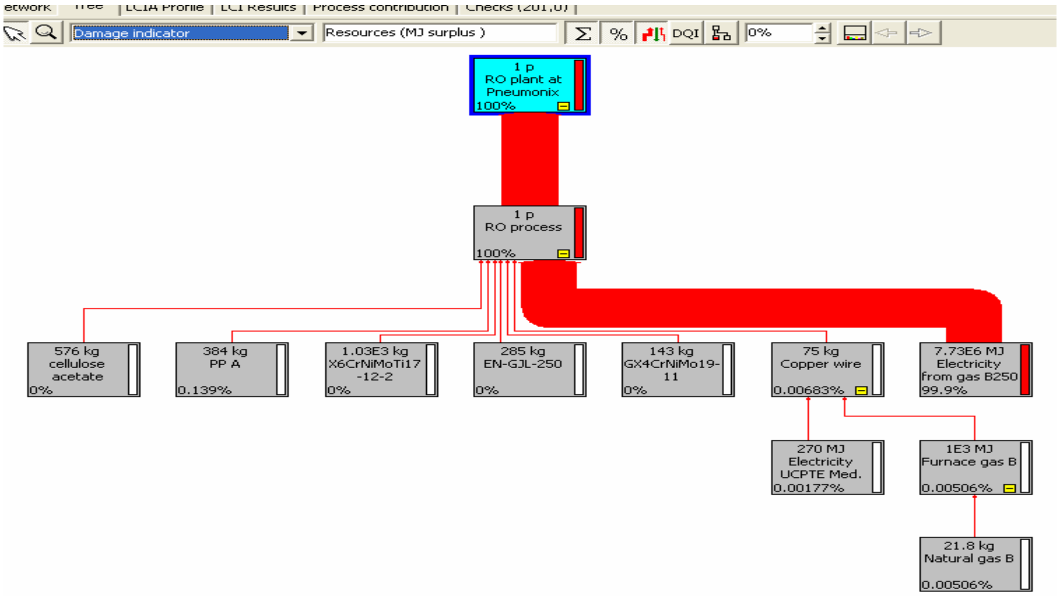


Fig 6.6: Tree's analysis output of RO plant at Numonyx to resources

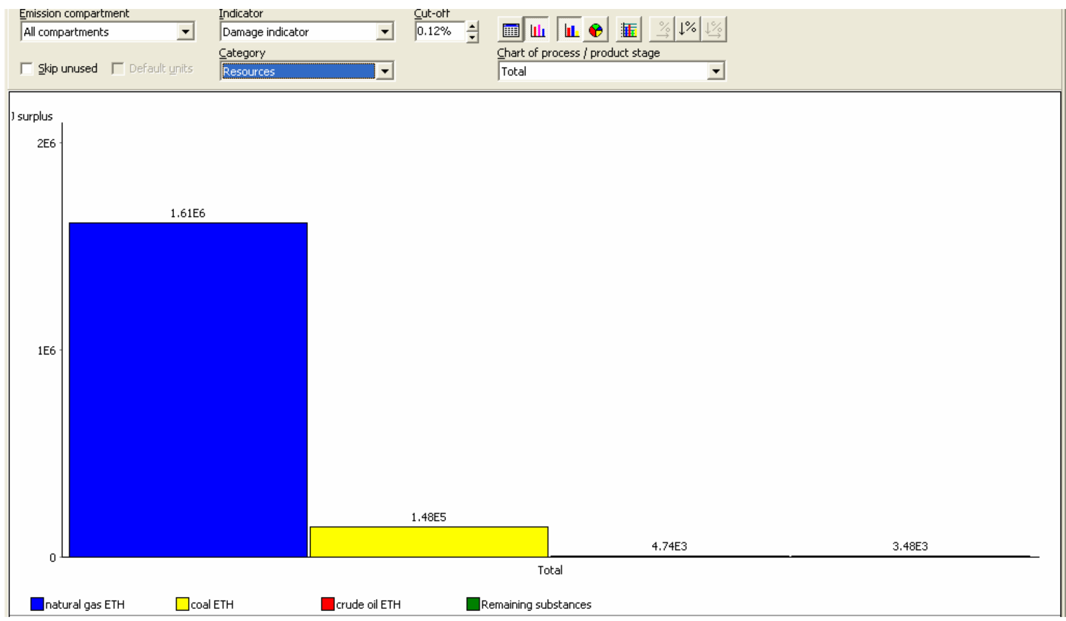


Fig 6.7: Damage indicator of RO plant at Numonyx to resources

Comments:

In Fig 6.6, electricity from gas with 99.9% is mainly used for RO pumps in the manufacturing process, which is the major contributor damage to resources. Fig 6.7 shows that natural gas is largely used during the process as it is the root cause to damaging the resources.

6.3.5 Damage to human health – UPW plant

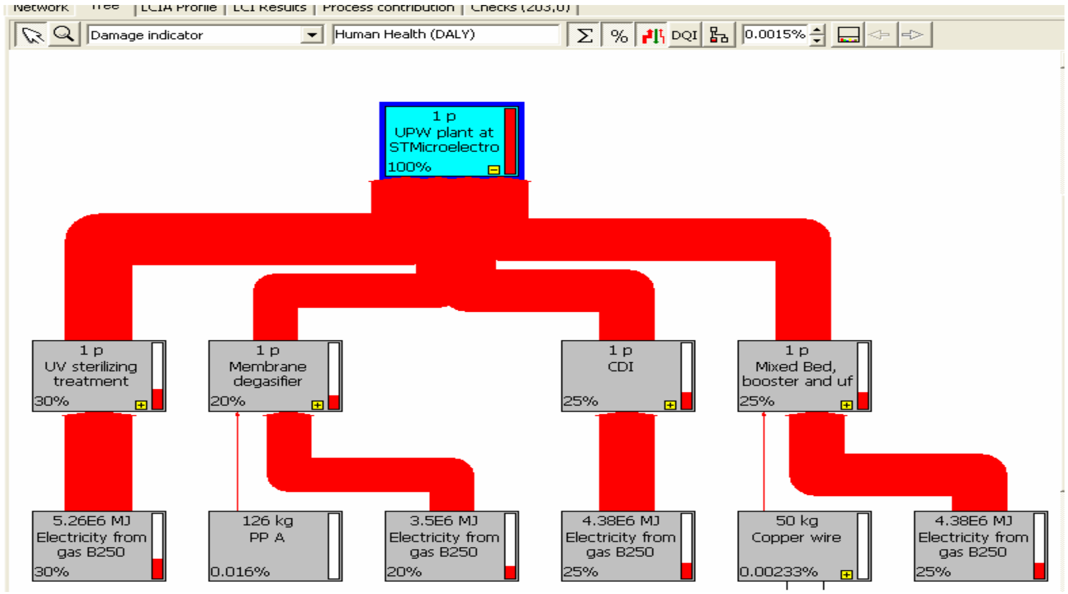


Fig 6.8: Tree's analysis output of UPW plant at STMicroelectronics Pte Ltd to human health

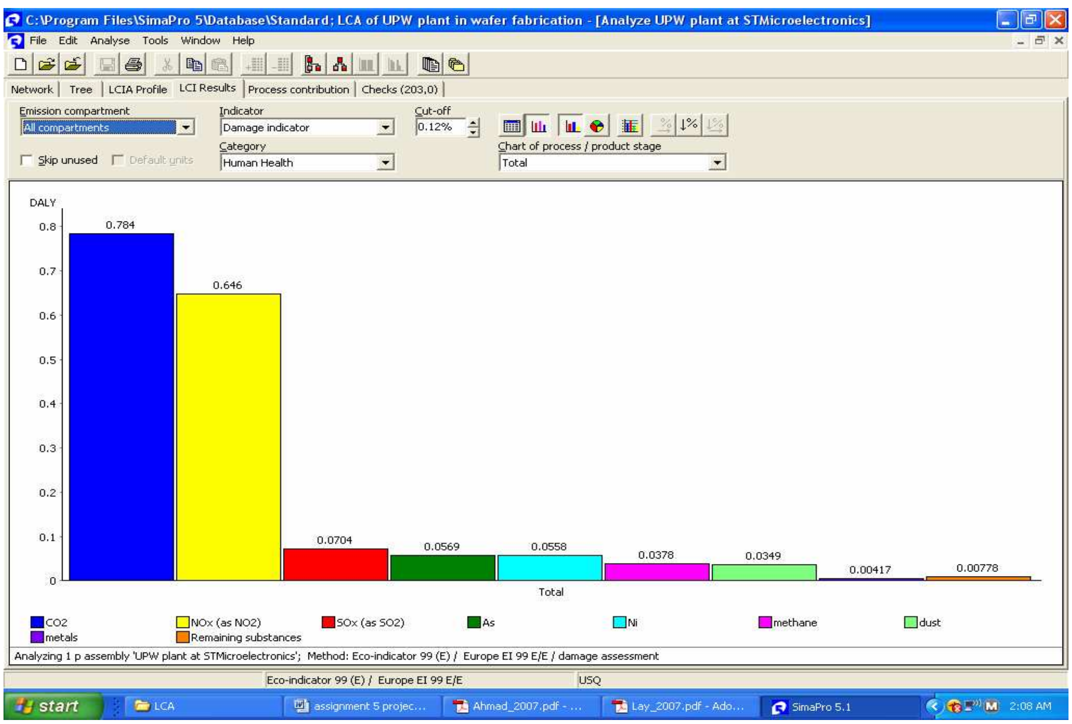


Fig 6.9: Damage indicator of UPW plant at STMicroelectronics Pte Ltd to human health

Comments:

The major contributor for the human health in the UPW plant at STMicroelectronics Pte Ltd is the electricity consumption by all the 4 processes as shown in Fig 6.8. Fig 6.9 shows that the CO2 and NOx caused the most damage to human health.

6.3.6 Damage to Ecosystem – UPW plant

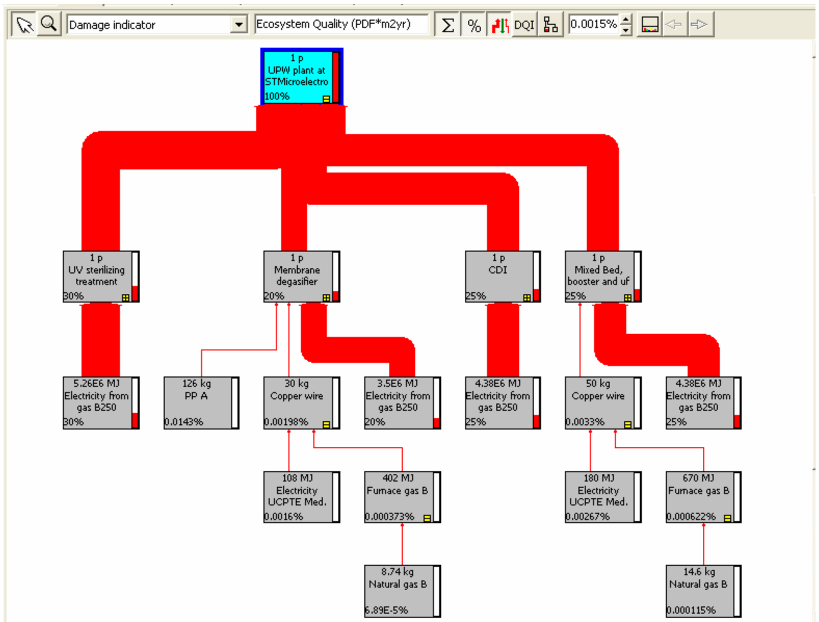


Fig 6.10: Tree's analysis output of UPW plant at STMicroelectronics to ecosystem quality

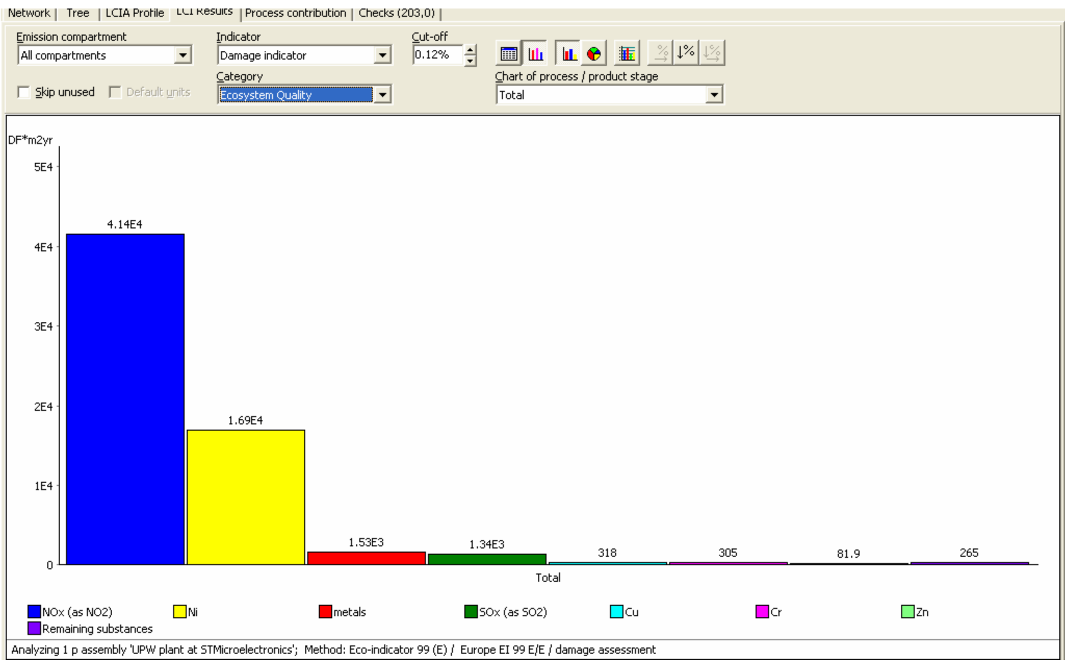


Fig 6.11: Damage indicator of UPW plant at STMicroelectronics to ecosystem quality

Comments:

The energy used by all the 4 processes is the contributor for the damage to ecosystem quality. Damage to ecosystem is caused by NOx and Nickel.

6.3.7 Damage to resources – UPW plant

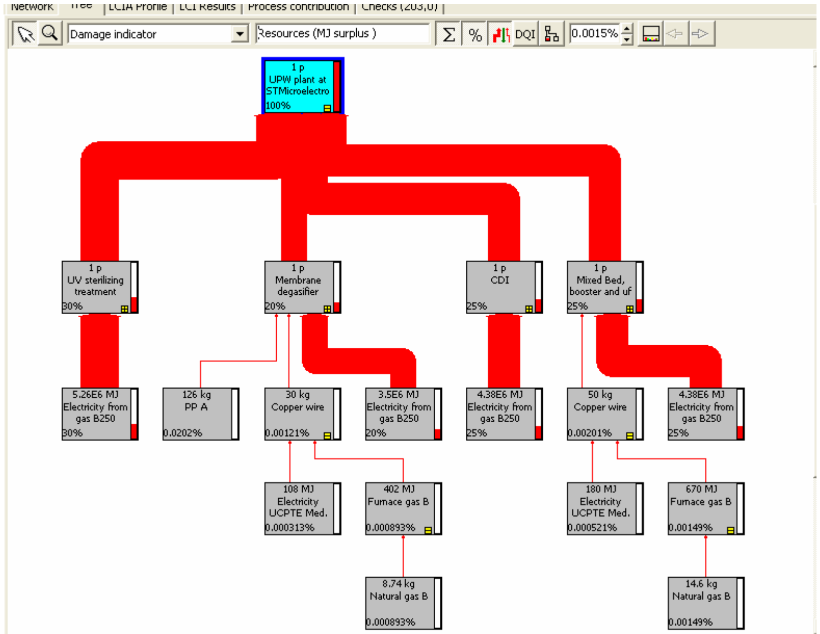


Fig 6.12: Tree's analysis output of UPW plant at STMicroelectronics to resources

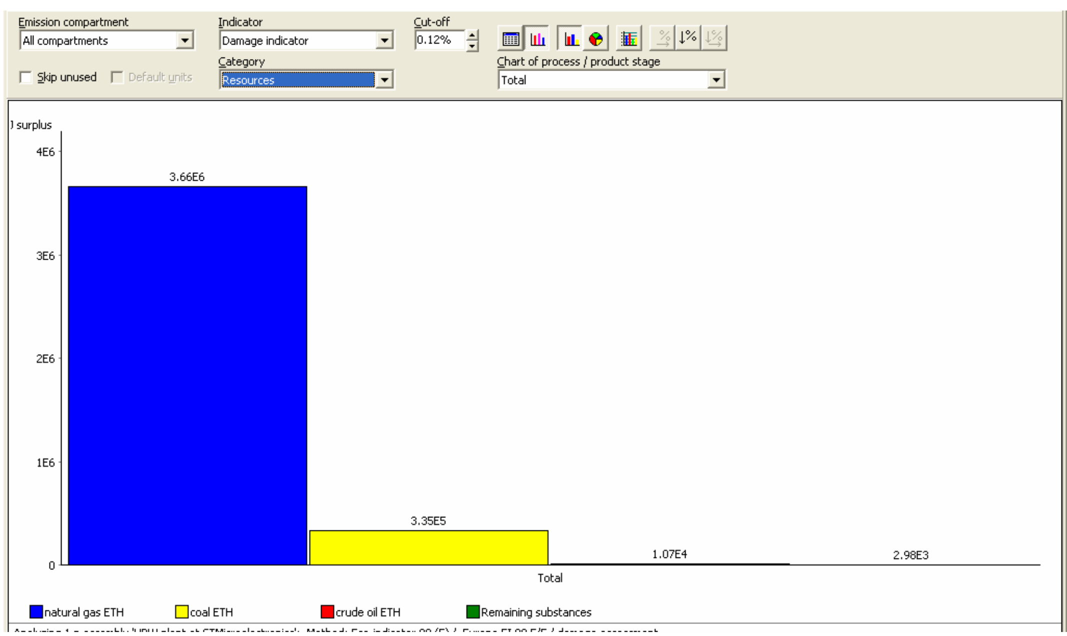


Fig 6.13: Damage indicator of UPW plant at STMicroelectronics to resources

Comments:

In Fig 6.12, electricity from gas is the major contributor damage to resources. Fig 6.13 shows that natural gas is largely used during the processes as it is the root cause to damaging the resources.

6.4 Identify Significant Issues in this LCA

UPW have been used in semiconductors for many years but no study on the life cycle assessment of the plant has been done. Comparison was made between waste water treatment and UPW production to make sure no irregularities or variance could influence the results of the LCIA.

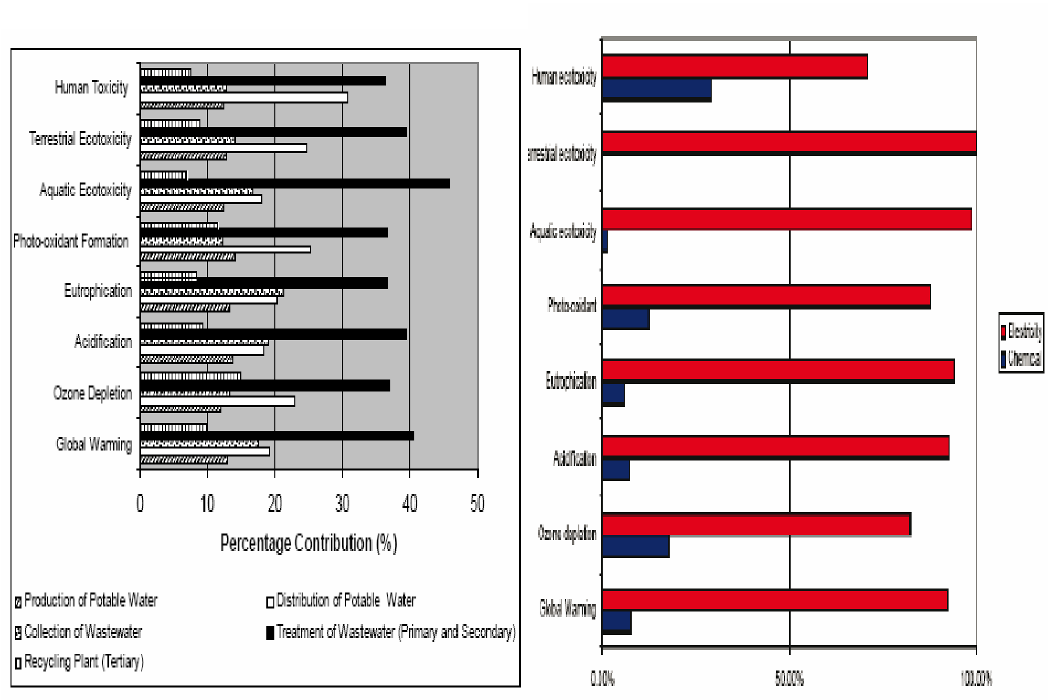


Fig 6.14: Impact categorization by process and energy contribution for waste water treatment

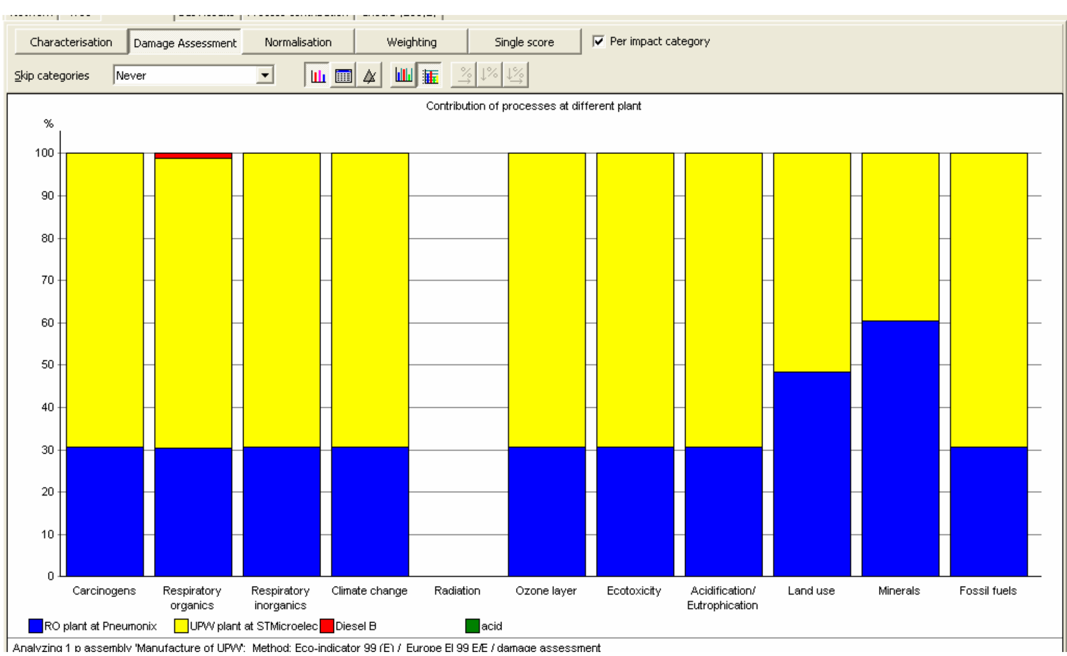


Fig 6.15: Damage assessment by impact category for UPW plant processes

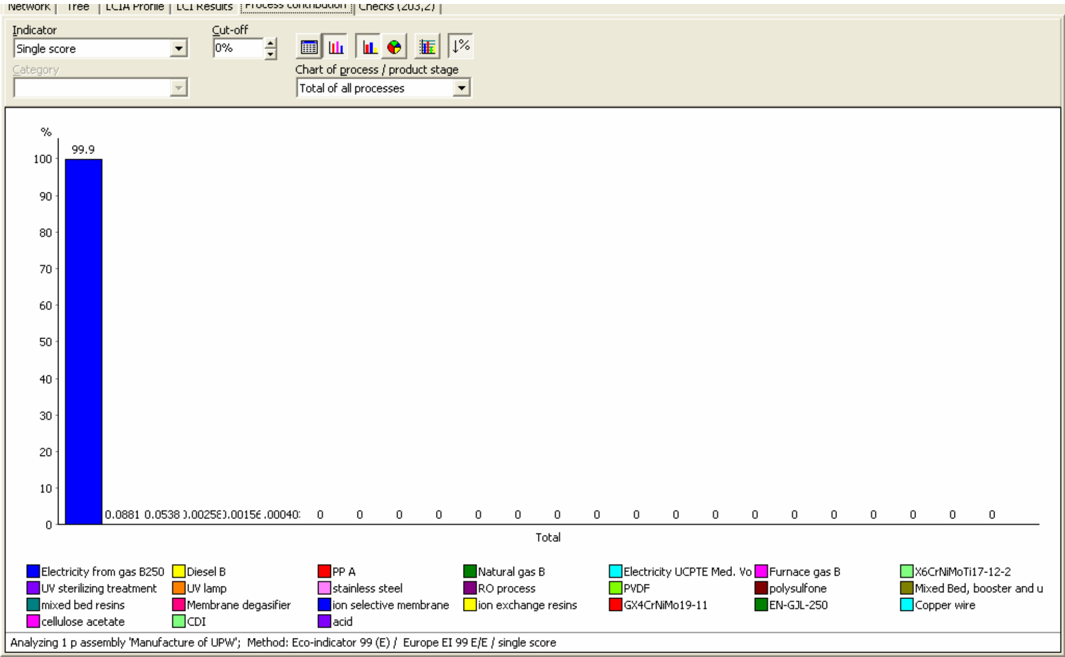


Fig 6.16: Single score output for total process contribution

Comments:

As seen in fig 6.14 and fig 6.15, the processes involve in treatment of waste water and UPW production does not affect radiation. Treatment of waste water and UPW production has the highest effect to the environment because it involved many processing steps. RO process has the least effect to the environment that can be compared with distribution of potable water, because it involved few or only 1 process step. The treatment of waste water and UPW production consume a lot of energy as shown in fig 6.14 and fig 6.16.

6.5 Evaluate issues in this LCA

To better understand the impact on the final results caused by the significant items as identified in the previous section, they are further evaluated here. A completeness consistency check was carried out so as to ensure the data used throughout this LCA study was in accordance with the goal and scope.

6.5.1 Completeness Check

Although this LCA study was carried primarily for educational purpose, every effort was made to ensure the accuracy and reliability of the inventory data. The completeness check was performed with the assistance from facilities and equipment engineers and technical experts. The process flow diagrams used for data inventory collection were inspected for any anomalies.

Data consumption inventories were thoroughly verified for any deficiencies and inaccuracy. Assumptions and estimations made to complete the inventory data were consulted and verified by the technical experts.

6.5.2 Sensitivity Check

The particular concern identified in the significant issue was the energy consumption from the life cycle inventory collection.

Uncertainty Analysis

The first step in conducting uncertainty analysis check is to identify and examine data for any possible irregularities or variance that could influence on the overall LCA results.

Since energy consumption is the highest contributor to the environmental impacts, its data was checked for accuracy. A sensitivity analysis on the electrical model was done to check for any influence on the overall LCIA results.

All other inventory items identified were analyzed and found that there are no irregularities found. This was due to their insignificant contribution to the environmental impacts.

6.6 Conclusion and Recommendations of this LCA

Results from the study showed similarity of life cycle impact assessment to LCA study on waste water treatment plant. Generally, it may be concluded that the interpretation stage has proved that the results obtained from other stages of the LCA are largely valid and in accordance with the goal and scope of this LCA study.

CHAPTER 7

Conclusions and Discussions

7.1 Introduction

This chapter basically summarized all the work that has been done for this LCA study. All major results are evaluated for its reliability and validation. Major assumptions and limitation are showed. Conclusions and recommendations are made and propose plans for future work are presented.

7.2 Accomplishment

The aim of the research project was to evaluate the severity of the environmental impact of a UPW plant in a semiconductor industry through Life Cycle Assessment. The results will be used to identify potential avenues for any improvement.

The research begins with conducting a literature review of water treatment plants from published literatures. After that, a better understanding of LCA history, ISO used, methodologies, limitations, benefits and uses were grasped. This is followed by the plant UPW process, definition of goal and scope and identification of the functional unit.

The next step involves data collections as part of the Life Cycle Inventory process and documented. The data were put into SimaPro for analysis. Finally the life cycle interpretation was conducted to establish accuracy and reliability of the LCI and its result.

7.3 Outcomes

The outcomes of this LCA study are summarized below:

- Almost two third of the impacts are linked to the UPW plant process at STMicroelectronics Pte Ltd. The rest of the impacts are linked to the RO process plant at Numonyx Pte Ltd.

- Majority of the environmental impacts from UPW plant are linked to the high energy demands from transfer pumps, UV sterilizing treatment, CDI, membrane degasifier and booster pumps.

- For RO plant, the major contribution comes from RO transfer pumps.

- The total energy consumption for UPW plant was two times more than for RO plant.

- The LCIA results proved that the highest contributing factors to the environmental burdens associated with UPW plant production can be linked to the high energy consumption of the process equipments.

- Even though water was used as the raw material to produce UPW, the amount of energy that comes from different process steps and materials used are costly.

- Chemicals used in UPW plant production is insignificant to the environmental impacts since the amount is little and it is mainly used for maintenance purpose.

- It was found by normalization chart that damage to ecosystem from UPW plant is the worst affected damage category.

7.4 Assumptions and Limitations

The limitation that surface during this project is the unavailability to get more information from the vendors. The data inventories are base on catalogues and manuals which are supplied to the company after project finishes. This is due to the reluctance from the respective vendors to release sensitive information.

Another limitation is the use of European inventory database instead of Asian database where the UPW plant is located. There was also a lack of clarity on data associated with the production of UPW. Thus most of the data used were substituted with the nearest possible data compared to the original data. This can make a difference in the impact assessment results.

7.5 Plans for future work

The initial plan was to conduct a life cycle assessment that includes the waste treatment of the UPW. However due to time and resource constraint, only the UPW production process has been carried out. Hence, future plans are to conduct life cycle assessment that includes the UPW waste treatment and disposal.

7.6 Recommendations

Electrical energy consumption to power up and maintain the UPW process equipments was found to be the major contributor to the damages done on the environment. This research project had identified the importance of energy conservation to reduce damage to the environment. The company's management acknowledged this and has plans to minimize energy consumption. It is advisable not to set up a RO plant in STMicroelectronics Pte Ltd to supply RO water to the UPW plant due to the return of investment takes a long time. The only measure that can be implemented is to shut down power to certain equipments in the process line but maintain the quality required. Normally this is done at the year end when there is an annual shutdown for facility robustness program or due to manufacturing ramp down.

The recommendations are based on the results of this LCA study. The final decision and implementation plans will be at the sole discretion of the company.

7.7 Final Conclusion

This research project was able to achieve most of the objectives set. The environmental impact associated with the UPW production plant was established with a certain degree of confidence. The LCA was done with accordance to ISO standards. The literature review from published literatures was reviewed to ensure this.

The life cycle inventory data was collected as accurately as possible. Anomaly assessments conducted ensure the reliability and validity of the life cycle inventory data. The research project was successful in assessing the environmental performance of UPW production plant through impact assessments done in Chapter 6. This could be useful information for researchers who wish to do LCA studies on similar product.

However, it should be reminded that this LCA study is done purely for educational purpose. LCA results presented in this dissertation are subject to the accuracy of the input data and various assumptions adopted in the model. The results of this project should only be used as an aid for decision making since LCA is an evaluative tool that helps decision making but it does not replace it.

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APPENDIX A – Project Specifications

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

FOR: Mohd Supandy

TOPIC: Environmental Life Cycle Assessment of Ultrapure Water (UPW)

SUPERVISORS: Dr Guangnan Chen

SPONSORSHIP: STMicroelectronics Pte Ltd

PROJECT AIM: The project aims to produce an outline of the Life Cycle Assessment to evaluate the environmental impacts caused by ultra-pure water (UPW) production in STMicroelectronic Pte Ltd facilities department.

PROGRAMME: Issue A , 10 Feb 2009

1. Research published literature on LCA technique to access environmental impact, origin of LCA, international standards used, LCA methodology, limitation, benefits, uses and software package being used.
2. Investigate UPW processing plant, equipments used and application in wafer fabrication. Review previous studies of LCA on water treatment or recycling process.
3. Define the goal and scope of LCA of UPW.
4. Collect and analyze the data for UPW process manufacturing using SIMAPRO.
5. Analyze input and output data for its impact on environment.
6. Check data for uncertainties and data gaps that need to be filled. Evaluate the result including problems and limitations. Make comparison with other studies to confirm the sensibility of the result.
7. Make recommendation on materials used and process involved and their environmental impact.
8. Identify and evaluate the opportunities for further improvements.

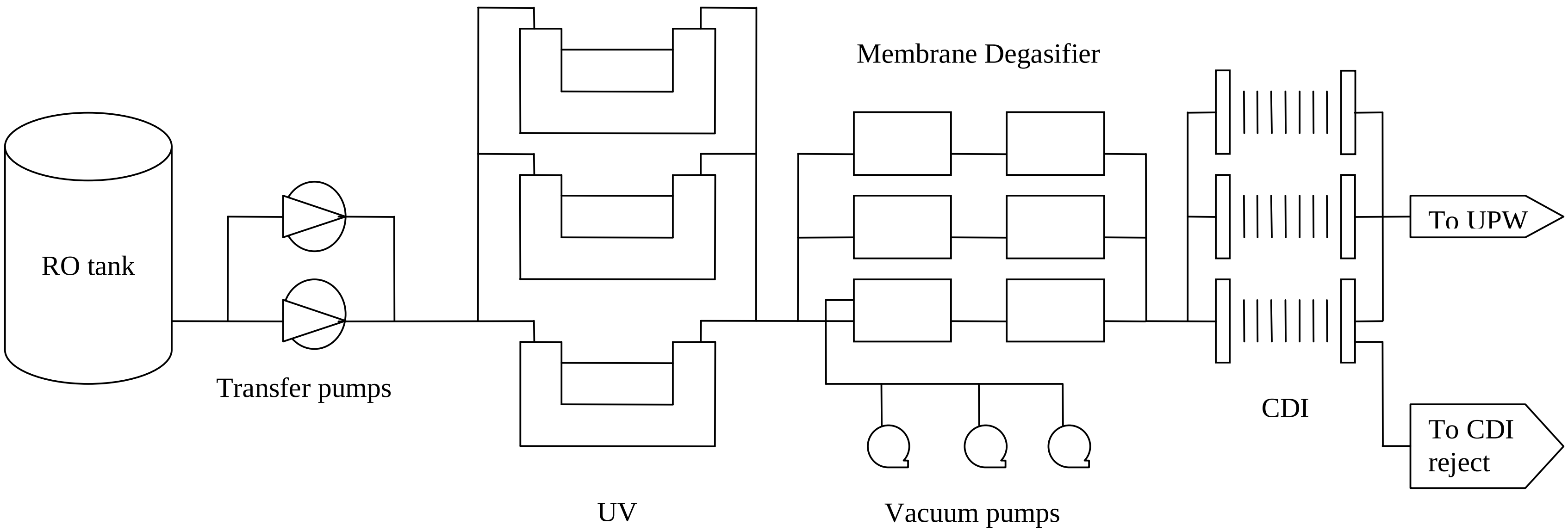
AGREED

________________ (Student) _________________, _______________(Supervisors)

___/___/___ ___/___/___ ___/___/___

APPENDIX B – UPW PRIMARY LOOP

PRIMARY LOOP



APPENDIX C – UPW POLISH LOOP

POLISH LOOP