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Prioritizing Actions in Alexandria's Urban Water System Based on Life Cycle Approach

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Master of Science Thesis
by
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Dedicated to

My beloved parents, my brother, and my sisters

Preface

This century can be considered as the century of water-related problems. Our traditional way of thinking about the water issues caused us a lot of troubles. So, there is a need for evolution of our way of thinking and for trying to find new ways of thinking in the water issues for better future.

Improving the current situation and finding new regimes for the urban water systems has become a must. Nevertheless, achieving that has to be preceded by assessment for the current situation to find out the main problems and the possible solutions. This research focused on the assessment of the urban water system in Alexandria City in Egypt, aiming to find the better ways for improving the system.

The research is one of the activities of the first theme of the SWITCH project (Sustainable Water management Improves Tomorrow's Cities' Health) which aims to achieve a paradigm shift in urban water management to get sustainable, healthy and safe urban water systems, where Alexandria city is one of the demonstration cities of the project. The SWITCH project is funded by the FP 6 programme of the European Union (No. 018530).

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Abstract

Urbanization, industrialization, and rapid population growth exerted very high stress in urban water systems that led to malfunctioning of these systems resulting severe environmental problems. This research focused on the assessment of the environmental impact of Alexandria's urban water system aiming to identify the hot spots of the system which enables the identification of the improvement potentials.

The life cycle assessment (LCA) methodology was used in order to achieve the goal of the research. A model for the system was constructed using the SimaPro software, and based on the Eco-indicator 99 assessment method the impacts of the system were analyzed.

The assessment of the system revealed that the wastewater treatment plants represents about 67% from the total impact of the system, most of the impact of the wastewater treatment plants was due to the discharge of nutrients-rich effluent into the water bodies. The water treatment plants represented about 18 % of the total impact; the impact of the water treatment plants was mainly due to the use of fossil fuel-generated electricity. A significant impact for the discharge of the untreated wastewater with about 7% of the total impact was reported. The transportation of water and wastewater showed less impact than the other compartments; their impact was 5%, and 2% from the total impact of the system respectively.

Improvement scenarios for improving the performance of the system are proposed, the proposed scenarios were in general: technical intervention, better management, and paradigm shift. The analysis of the proposed scenarios showed that the paradigm shift caused the highest reduction in the total impact of the system. Moreover, a combination of the scenarios caused more reduction in the system impact.

The research showed that two solutions could improve the system. The first solution is the use of activated sludge in addition to the reduction of the losses in the distribution network and reduction of the water consumption; this solution can decrease the total impact of the system by about 66%. The second solution is similar to the first solution, the only difference is the use of paradigm shift (decentralized wastewater treatment for domestic wastewater and activated sludge for industrial wastewater and storm water) instead of the activated sludge used in the first solution; this solution can decrease the total impact of the system by about 76%.

It was recommended that a study includes the economic and social dimension in addition to the environmental dimension has to be carried out for drawing a complete picture about the system.

Keywords: Life cycle assessment (LCA), Alexandria, urban water system, environmental impact, and paradigm shift.

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1 Introduction

Urbanization, industrialization and rapid population growth in developing countries are putting increasing pressure on local water authorities and water planners to satisfy the growing urban water and sanitation demands. It is clear that the conventional approaches of urban water management for providing these essential services are costly, insufficient, and are not integrated. Hence, there's a need for finding new ways for improving the urban water systems to enable better management of these systems.

The identification of the potential ways for improving the urban water systems has to be based on precise assessment for these systems. In this context the life cycle assessment (LCA) can play a vital role in assessing the urban water systems in a holistic way that enables the identification of the critical processes and the improvement potentials of the system.

LCA is emerging as one of the tools of cleaner production. It is the only tool which has a cradle-to-grave approach and by this it avoids positive ratings for measures which only consist in the shifting of (environmental) burdens (Kloepffer, 1997). Therefore, it provides a holistic view of the environmental impacts due to a product, service or activity. The LCA methodology enables the calculation of environmental burdens in a systematic and scientific way by regarding all the inputs and outputs of a system. Hence, it allows for comparison on environmental grounds.

So, due to the unique characteristics of LCA, this tool will be used in this research to assess the environmental burdens resulting from different components of the urban water system in Alexandria city in Egypt. The use of the LCA will provide better understanding of the system which enables the identification of the different options for improving the system, which can provide the decision makers with a powerful tool for more sustainable management of the system.

1.1 Background

Located in the north of Egypt on the Mediterranean Sea, Alexandria (Figure 1.1) is the second most important city in Egypt after Cairo with a population of about 3.7 millions (AGPP, 2006). It is the main harbour and the most popular summer resort for Egyptians. It is the second most important industrial centre in Egypt; Alexandria hosts nearly 37% of Egypt's industries (large oil refineries; chemical, cement, and metal plants; textile mills; and food processing operations), and nearly 40% of the working sector is employed by the industrial sector (UNDP, 2003).

Alexandria's urban water system is subjected to very high stress due to the high domestic and industrial use of the water, and hence huge amounts of wastewater are resulted out of the system which has to be handled. This high stress leads to malfunctioning of the system which

resulted in environmental, social, and financial problems, while the environmental problem is considered the main driving force behind all the other problems.

The environmental problem in Alexandria is mainly pollution problem due to the discharge of all kinds of wastewater into the water streams (Lake Mariout and Mediterranean Sea) such as: domestic wastewater (untreated or primary treated), industrial wastewater, agriculture drainage water. The pollution problem has the following consequences: negative impact on Lake Mariout ecology, decrease of the capture fish in Lake Mariout, eutrophication problems in Lake Mariout. The aforementioned problems lead to social problems especially on the fishermen; it could also results negative impacts on the human health.

In addition, some of the slum areas and the sub-urban areas are in lack of the basic sanitation facilities and some areas are in lack of drinking water facilities (AGPP, 2006), hence the system has to be expanded to include these areas. The expansion of the system depends on the financial resources of the local government that usually look for the lower cost with high performance and with less environmental impact.

So, it is obvious that the system is very problematic and requires improvement for achieving the sustainability. For this reason the improvement of the system has been a great concern of the government and the public. Thereof, this research acquires its importance as a tool for assessing the system and hence enables the improvement of the system sustainability in a holistic way.

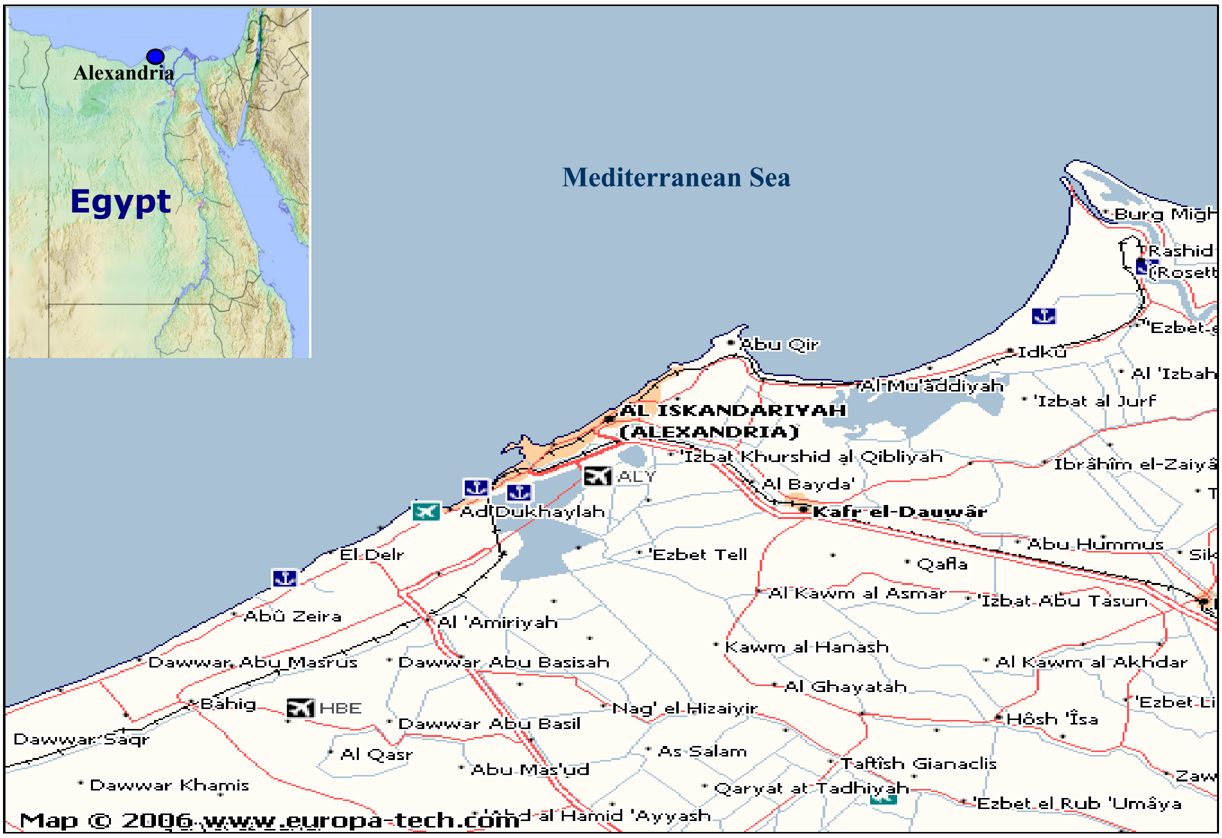

Figure 1.1: A map of Alexandria.

1.2 Goal and scope definition

1.2.1 Defining the goals of the research

The main goal of the research is improve the total environmental performance of Alexandria's urban water system. Therefore the specific objectives of the research are:

- To assess Alexandria's urban water system using the LCA,
- To propose the possible scenarios for improving the environmental performance of the system, and
- To compare the burdens associated with the current situation and the alternative scenarios in order to find out the better scenario.

This research can help in achieving the following aims:

- Developing a master plan for the future improvement of the system, and
- Guiding designers and decision makers on the full life cycle consequences of the system, and to alert them to the benefits of using full life cycle assessments in the selection of the system components.

1.2.2 Defining the scope of the research

The system under research is the urban water system of Alexandria City in Egypt; including: water treatment plants, water distribution system, wastewater treatment plants and the sewerage system. In this research the operation phase only will be taken into consideration in carrying out LCA because it is the dominant phase (has the highest contribution to the total impact of the life cycle) in the waterworks (Friedrich et al., 2001, and Sven et al., 2004).

The main functional unit which will be used in the research is the delivery of one cubic meter of potable water (one cubic meter at the effluent of the water treatment plant) or treatment of one cubic meter of wastewater which is commonly used in this field. The same functional unit used by Mario et al. (2001), Teng (2006), and Sven et al. (2004), whilst Stephane et al. (2005) used a functional unit of 1 cubic meter of water at the tap of the consumer due to the fact of the presence of the leakage in the distribution system and that not all the consumed water is treated.

1.3 Description of Alexandria urban water system

Alexandria receives its fresh water from the River Nile through Mahmoudia Canal; the water is then treated through 7 water treatment plants of a capacity of about 2.3 million cubic meters per day. The drinking water is transported to the users through the distribution network and by the aid of 43 booster stations to be used in both domestic and industrial use.

The wastewater resulted from the users is collected in a combined sewerage system which collects both domestic waste and partially treated industrial waste in addition to the storm water. The collected wastewater is then discharged to four wastewater treatment plants (WWTPs) of a capacity of about 835,000 cubic meters per day by the aid of 39 pump stations distributed in different places in the city. The treated wastewater is discharge to Lake Mariout then it is being pumped out to the Mediterranean Sea or it is discharged to drains that end up in the sea. A fraction of the collected wastewater is discharged to the sea through some drains without any kind of treatment. Moreover, about 47000 m^3/d of industrial wastewater is discharged directly into Lake Mariout (Masaoud, 2002).

The sludge resulted from the water treatment is partially discharged to Mahmoudia Canal and partially to the sewerage network, while the sludge resulted from the wastewater treatment is treated and reused in land application. Figure 1.2 shows a schematic of Alexandria's urban water system. Detailed description of the different compartments of the system is introduced in the following sections.

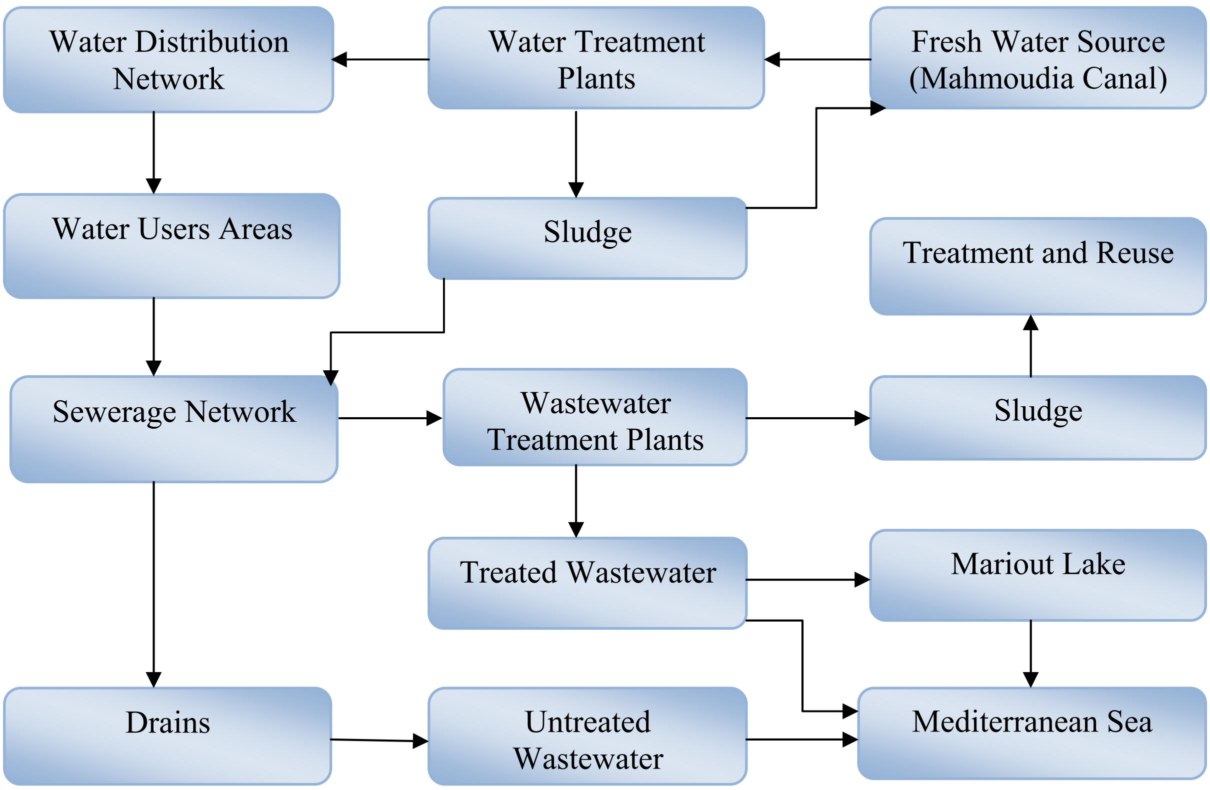

Figure 1.2: Schematic of Alexandria's urban water system.

A map shows the approximate locations of the water treatment plants (WTPs) and the wastewater treatment plants (WWTPs) within the city of Alexandria is shown in Figure 1.3.

Figure 1.3: A map shows the approximate locations of the WTPs and WWTPs in Alexandria.

1.3.1 Drinking water system

The water system covers an area that is approximately 340 km from east to west and 125 km, north to south. Seven water treatment plants collectively supply 2.3 million cubic meters of drinking water per day, the capacity of each of these plants is shown in Table 1.2. The water is conveyed to Alexandria's inhabitants through almost 6,500 kms of pipe, with 43 booster pump stations and 33 storage reservoirs (USAID, 2005).

Table 1.1: Average capacity of the water treatment plants.

Plant	Actual capacity (m^3/d)
Nozha treatment plant	120,000
Seaouf treatment plant	750,000
Bab Sharky treatment plant	400,000
Manshia treatment plant	600,000
Maamoura treatment plant	150,000
Mariout treatment plant	320,000
Forn El-Geraya treatment plant	60,000

1.3.1.1 Water treatment plants

The seven water treatment plants are now working using the same treatment system. The raw water is primarily pumped to the clarifier where three steps are carried out, firstly the flash mixing step where the coagulant is added and mixed with the water in this step also chlorine

is added to kill the algae (pre-chlorination), then the flocculator step where also the water is mixed but with medium speed for allowing converting the suspended solids into flocs which is settled in the third step in the sedimentation basin. The water is then filtered using rapid sand filter and then additional chlorine is added to disinfect the water (post-chlorination) then the water is stored in the storage tanks before it is pumped out (using the clean water pumps) to be distributed to the users through the distribution network. A schematic drawing of the treatment system is shown in Figure 1.4.

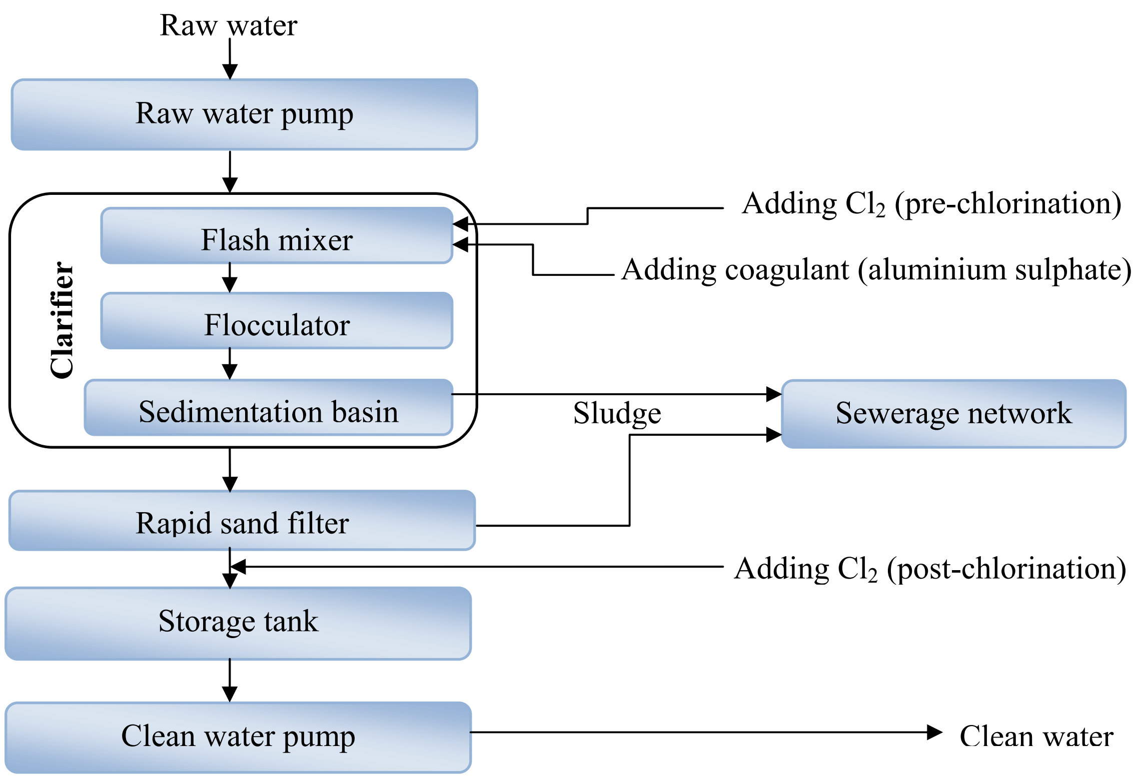

Figure 1.4: Schematic of the water treatment process.

1.3.2 Wastewater system

The system consists of two primary WWTPs (west treatment plant and east treatment plant) and two secondary WWTPs (Eskan Mubark and Hanoville). However, the primary ones are considered the main units where most of the wastewater is treated, while the secondary ones are very small. Table 1.1 shows the average actual capacity and the design capacity of the four WWTPs.

Table 1.2: Capacity of the four WWTPs.

Plant	Type	Actual capacity (m^3/d)	Design capacity (m^3/d)
West WWTP	Primary treatment	450000	607000
East WWTP	Primary treatment	350000	462000
Eskan Mubark	Secondary treatment	15000	15000
Hanoville WWTP	Secondary treatment	20000	20000

1.3.2.1 East and West treatment plants

Both plants are primary treatment plants with almost the same operation and design scheme except few minor differences. In both of them the wastewater is pumped either from pump stations out the plant as in the case of the east treatment plant or from a pump station inside the plant itself (which receives water from other pump stations) as in the case of the west treatment plant. The wastewater then passes through bar screens to remove the big particles and floating big particles, and then it goes to the grit removal chamber to remove the grit before going to the flow split chamber which distributes the flow to the primary sedimentation tanks.

The primary sedimentation tanks are the main treatment unit which treats the water with a removal of about 30% in the east treatment plant and about 60% in the west treatment plant. The big difference in the removal efficiency is due to the fact that the sludge resulted from the east treatment plant is diluted and then pumped to the west treatment plant; this sludge is already treated so it can be settled very quickly in the west treatment plant.

The water resulted from the sedimentation tanks is then passes through effluent screening facility before it discharges to the Lake Mariout. The sludge resulted out of the treatment process is pumped to the sludge dewatering unit to be dewatered. Figure 1.5 shows the flow chart of the two plants.

The sludge dewatering unit is located beside the west treatment plant. The process of dewatering the sludge begins with mixing the sludge in equalization tanks to homogenize the sludge, then the polymers are added to the sludge for facilitating the settling of the sludge (separation of the sludge from the water), and by the mean of a belt press the sludge is compressed to raise the density from about 3 % at the treatment plant to about 28 % after the dewatering. The treated sludge is transported to the disposal site where it is being composted and then sold to the farmers to be used as fertilizer.

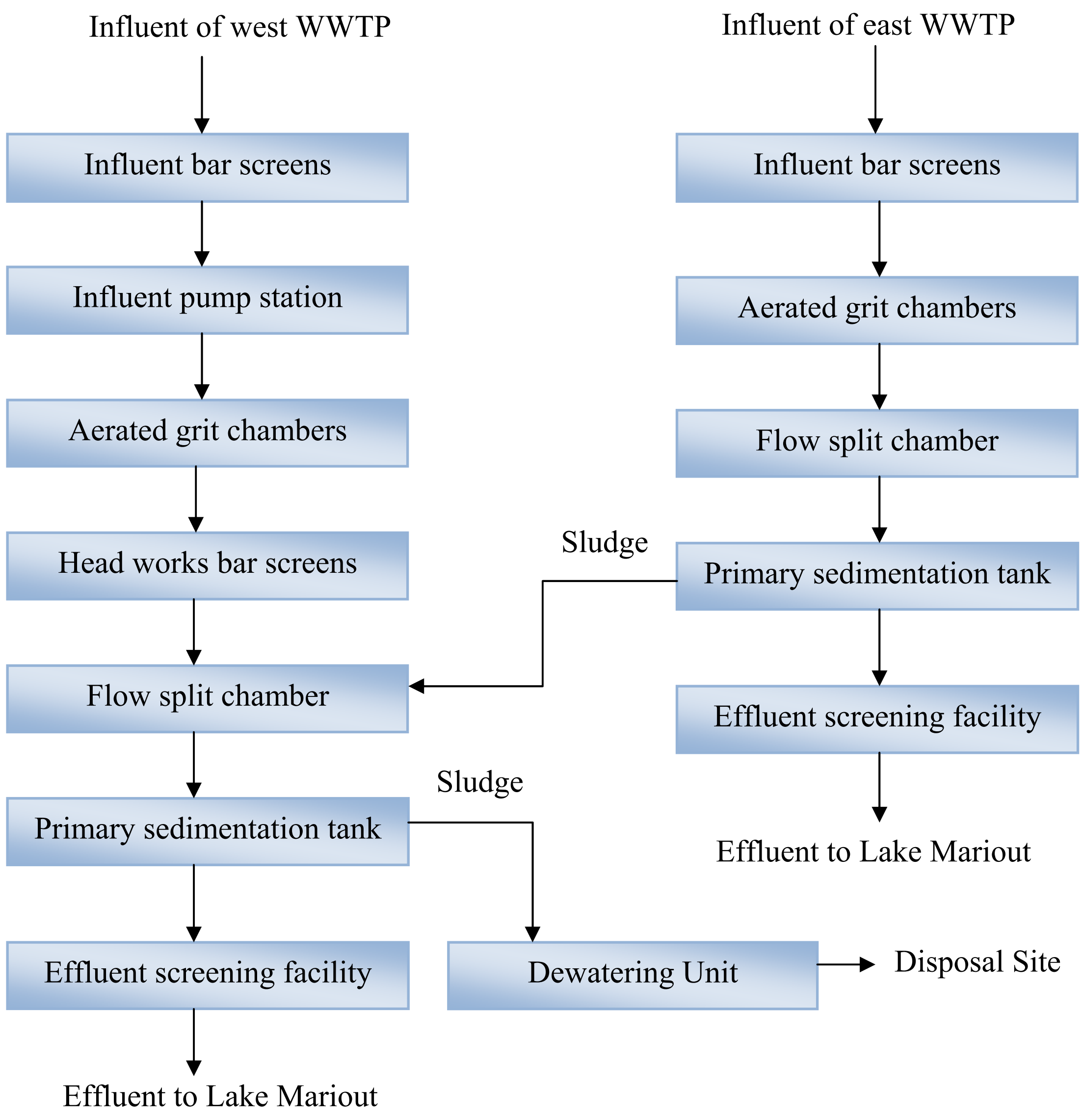

Figure 1.5: Schematic of the treatment process in the east WWTP and the west WWTP.

1.3.2.2 Eskan Mubark and Hanoville plants

Eskan Mubark plant was built to identify the best treatment technology that can be appropriate to be used in Alexandria. The plant have three types of technologies, those technologies are: micro-filtration (4000 m^3/d), sequence batch reactor with extended aeration (5000 m^3/d), and intermediate cycle extended aeration system (6000 m^3/d). The last two technologies have been chosen to be most suitable in Alexandria, so they are used in Hanoville plant with a capacity of 10000 m^3/d in each unit.

The treatment process starts by passing the water through bar screens and then through the grit removal chamber, then the water goes to the main treatment step which is one of the mentioned technologies. In the micro-filtration system the water flows through filters with pore size of about 6 micron where the BOD is removed with the aid of a very high MLVSS of about 11000 mg/l. In the case of sequence batch reactor, the tank is filled with wastewater,

and then aeration takes place in the same tank which helps to accelerate the sedimentation of the organic matter then the treated water is taken from the top of the tank which will be filled again with water to repeat the process for another batch. The intermediate cycle extended aeration system is the same as the previous one but the flow is continuous

The treated wastewater is discharged to Amria drain which ends up with the Mediterranean Sea, while the sludge is stored in aerated storage tanks for about 3 months to be stabilized and then it is dried by the aid of polymers before it is transported to the disposal site. Figure 1.6 shows the general flow diagram of the two plants

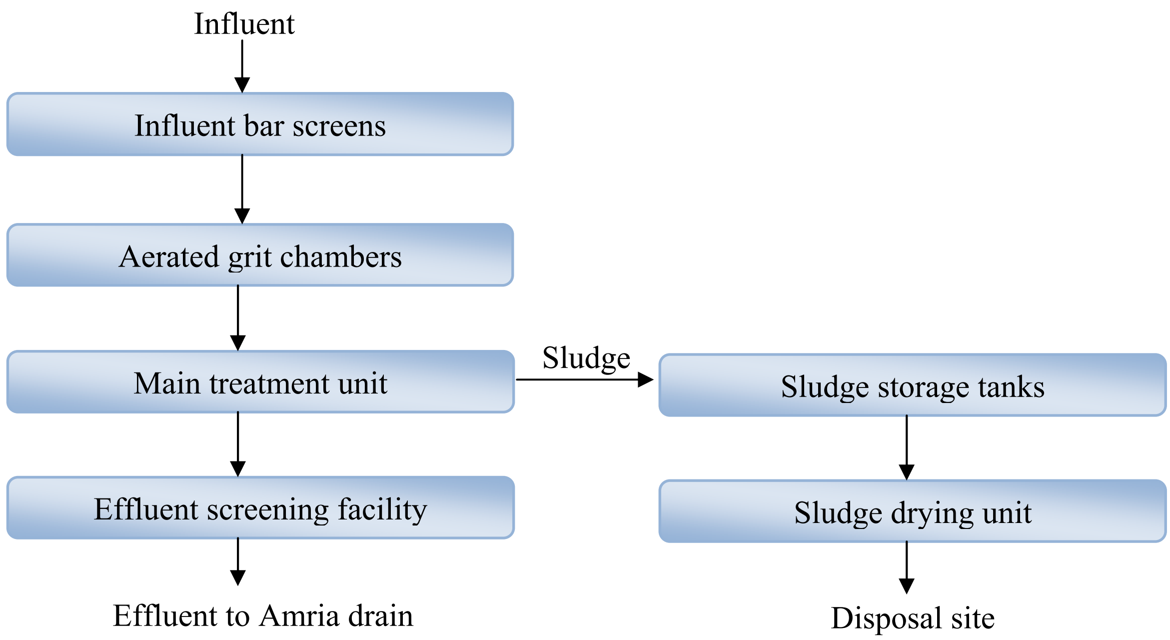

Figure 1.6: Schematic of the secondary treatment plants.

2 Literature Review

In this chapter the LCA definition and methodology as mentioned in the literature, and the studies used the life cycle approach in assessing urban water systems will be presented.

2.1 LCA definition and methodology

2.1.1 LCA Definition

The definition of the LCA given by the International Organization for Standardization (ISO) in the ISO-14040-1997 standard and cited by Astrup et al. (1997) is as follows:

> *LCA is a technique for assessing the environmental aspects and potential impacts associated with a product, by:*
>
> - *Compiling and inventory of relevant inputs and outputs of a system,*
> - *Evaluating the potential impacts associated with those inputs and outputs,*
> - *Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study.*
>
> *LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw materials acquisition through production, use and disposal. The general categories of environmental impacts needing consideration include resource use, human health and ecological consequences.*

It is important to note that an LCA can be applied as well over the life cycle of services, processes and other general activities, and must not be limited to products. It has to be emphasized also that as any other tool, LCA supports environmental decision making, but does not replace other tools; rather than that, it provides additional, quantitative and objective information for a specific application (Barrios, 2004).

The technique differs from other environmental tools in a number of significant ways (UNEP, 1996):

- It can be used to study the environmental impact of either a product or of the function a product is designed to perform,
- It provides objective data which are not dependent on any ideology, and
- It is much more complex than other environmental tools.

In addition, it is mentioned in the same report (UNEP 1996) that LCA depends on scientific data and is a quantitative tool designed to provide the most objective information possible to support the decision-making process. Among the main reasons they mentioned to use LCA are:

- Intuition is not enough [to analyze complex problems],
- It gives reproducible answers, and
- It enhances credibility.

LCA is free of value judgments like ‘electrical transport is better than the conventional one’. This kind of sentence has many problems, since it is an opinion based mainly in intuition and does not consider the whole life cycle of the service. Electrical transport seems to be ‘clean’ or ‘environmentally friendly’ in the place it runs, but very often that opinion does not consider the fact that electricity must be produced somewhere. In this form the problems (like pollution, environmental risk, safety, etc.) are shifted from the place of energy consumption (electrical transport) to the place of energy production (power plant). (Barrios, 2004)

Using life cycle approaches will avoid the commonly encountered ‘problem shifting’. Problem shifting means that, while trying to solve a problem, this problem is not fully solved but instead (partially) shifted: from one stage of the life cycle to another, from one location to another, from one environmental medium (e.g. air, water, or land) to another medium, or from the present to the future (UNEP, 2005)

2.1.2 LCA Methodology

LCA methodology from the ISO-14040-1997 standard and cited by Barrios (2004) has four main phases (Figure 2.1):

I. Goal and scope definition
II. Inventory analysis
III. Impacts assessment
IV. Interpretation

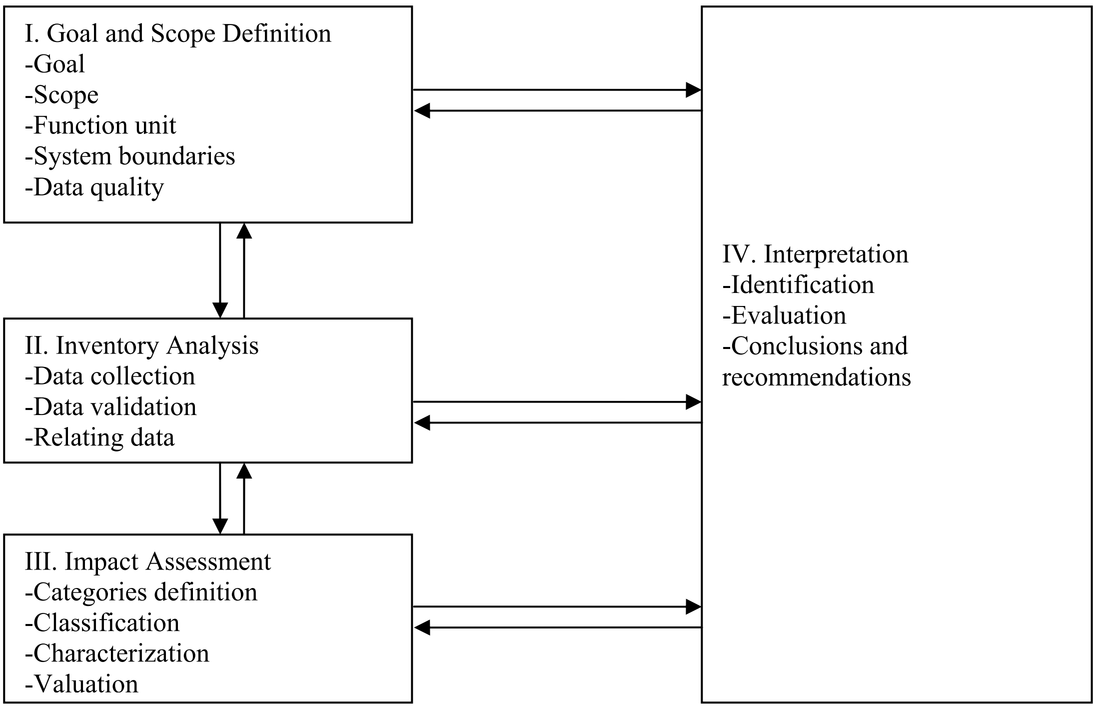

Figure 2.1: LCA phases (ISO 1997a, cited by Teng 2006).

I. Goal and Scope Definition

The goal and scope definition is the first phase and the critical part of an LCA due to the strong influence on the results. It includes the following elements:

i. Goal definition: In the goal definition it is very important to define the purpose of LCA. The goal has to state obviously the intended applications and the users of the results. LCA goals can be: the comparison of two different products doing the same function, the identification of the potential improvement of existing product, etcetera. “The goal can be redefined as a result of the findings throughout the study”. (Astrup et al., 1997)

ii. Scope definition: The scope defines the borders of the assessment and the assessment method. The scope has to be well defined to ensure that the study is compatible with the stated goal. "LCA is an iterative technique. Therefore, the scope may need to be modified during the study as additional information is collected”. (Astrup et al., 1997)

iii. Functional unit: Functional unit definition is the base of LCA because it sets the scale for the comparison between two or more products. The data that have to be gathered in the inventory phase is very dependent on the functional unit. In addition, functional unit provides a reference for normalization of the input and output data. An example of the functional unit commonly used in urban water field is one cubic meter of drinking water produced or treated.

iv. System boundaries: System boundaries define the unit processes (operations), inputs, and outputs that will be considered in the study. The definition of system boundaries is subjective process and can contain the following boundaries: geographical boundaries, LCA boundaries (limitations), temporal boundaries. The system boundaries greatly affect the results of the study and the time and resources needed, so any omission in the life cycle stages should be clearly stated and justified. (Astrup et al., 1997)

v. Data quality: The quality of the data that will be used in the inventory phase will be reflected on the final results of the LCA. The data quality should be described and assessed in systematic way that allows others to understand and control the quality of the actual data. The data collection depends on the time-related coverage, geographical coverage, and technology coverage.

II. Inventory analysis

Inventory analysis is the second phase in LCA and contains the following elements:

i. Data collection: Data collection aims to make an inventory of energy and material consumption (the use of resources), wastes production, and emissions during the life cycle of the process or the product. Data collection must include all the single processes within the system boundaries.

Data collection is often the most work intensive part of the LCA. Average data from literature can be used specifically in case of well known and common processes. For instance, hydrochloric acid is used in water treatment, but it is very commonly used in the industry, therefore its environmental impact is known. (Astrup et al., 1997)

ii. Data validation: Data validation has to be conducted during the data collection to increase the overall data quality. Systematic data validation may reveal areas where data quality has to be improved. Methods such as mass balance, energy balance, and comparative analysis of emissions can be used to validate the data.

iii. Relating data: Relating data accomplished by normalizing input and output data collected for each unit process to the functional unit.

In order to be reliable, the inventory produced during this stage should meet some basic criteria, mainly the following (Astrup et al., 1997):

- Comprehensive: all the significant energy and materials uses, as well as emissions are included.
- Detailed: is conducted in a manner and to a level of detail commensurate with the purpose of the study.
- Peer reviewed: If the study results are to be used in a public manner, they should be peer reviewed using accepted protocols.
- Quantitative: data should be quantitative and documented with quality control. Any assumption must be specified.
- Replicable: the sources of information and methodology are described in such a way that the same results should be obtained by any skilled person.
- Scientific: Scientific based analysis is used to obtain and process the data.
- Useful: user of the study can make appropriate decisions in areas covered by the inventory.

III. Impact assessment

Impact assessment is the third phase in the LCA. In this phase the environmental impacts identified during the inventory data collection are classified and quantified according to their impact on the resources, environment, and human health. The following elements are the main elements in this phase:

i. Category definition: It involves the definition of the impact categories that will be considered. Numerous impact categories have been proposed for LCA. The selection of the impact categories is based mainly on the goal and scope definition. The following criteria have to be addressed in the selection of the impact categories:

  - Completeness: all relevant environmental problems should be covered in the lists.

- Practically: the list should not contain too many categories.
- Independence: double counting should be avoided by choosing mutually independent impact categories.
- Relation to characterization step: the chosen impact categories should be related to available characterization methods.

The impact categories commonly considered are:

- Abiotic resources
- Biotic resources
- Land use
- Global warming
- Stratospheric ozone depletion
- Ecotoxicological impacts
- Human toxicological impacts
- Photochemical oxidant formation
- Acidification
- Eutrophication

ii. Classification: In this element the inventory input and output data are assigned to the related impact categories defined in the previous step. Some outputs contribute to different impact categories and therefore, they have to be mentioned twice (e.g. NO_x emissions are toxic, acidifying and cause eutrophication). The resulting double counting is acceptable if the effects are independent of each other whereas double counting of different effects in the same effect chain is not allowed, e.g. stratospheric ozone depletion and human toxicological effects on skin cancer (Astrup et al., 1997).

iii. Characterization: characterization is to quantify the potential contribution by the inputs and the outputs of the system to the selected impact categories. This is done by assigning by using equivalence factors for each input and output, for example the equivalence factor for CH_4 given by Eco-Indicator 97 in case of global warming is 21, while for CO_2 the factor is 1. That means that the effects from the emissions of 1 kg CH_4 are equivalent to the effects from the emission of 21 kg CO_2 with respect to global warming.

iv. Valuation or weighting: The previous step provides a set of scores on impacts categories of the product or the process. However, direct comparison of theses scores is not possible. So, weighing is done to reflect the relative importance of these scores in order to rank or aggregate the results from the chosen impact categories. Hence, the characterization scores are multiplied by the weighing factor for each impact category.

The valuation is considered the weakest part of the LCA, since it is not technical, scientific or objective as the ISO-14040-1997 standard mentions. “Validation or

weighting is a qualitative or quantitative step, not necessarily based on natural science but often on political or ethical values". (Astrup et al., 1997)

This problem can be solved by applying scientifically based analytical techniques (Astrup et al., 1997). The main weighting methods developed by different institutions are:

- Proxy approach
- Technology abatement approach
- Monetarisation
- Authorized goals or standards (distance to target)
- Authoritative panels (societal approach)

In this research the assessment method that will be used is Eco-Indicator 99. The weighing method that is used in Eco-Indicator 99 is what is called "Authoritative panels" which based on a survey of a panel of experts from which the weighing factors can be assigned to the different impact categories. An example for the calculations of the impact assessment phase is presented in Annex F.

IV. Interpretation

Interpretation is the fourth phase of LCA. The aim of interpretation is to facilitate the decision-making process based on the LCA. It consists of three steps which are:

- Identification of significant issues
- Evaluation
- Conclusions and recommendations

The significant environmental issues of the study may be contributions to global warming or ozone depletion, emissions of chemical compounds like NO_x, etc. In the evaluation step, qualitative checking of input data and quantitative analysis of any implication of changes in input data are done.

2.2 Overview of studies that used the life cycle approach for evaluating urban water systems

Several publications exist where LCA or related methods have been applied to evaluate the urban water systems either the whole system or part of the system. Here after, different approaches are summarized and compared according to their scope, system boundaries, and the main findings of each.

2.2.1 Studies carried out on the whole urban water system

The use of LCA in the field of urban water management still very limited especially in the case of the assessment of the whole urban water system. The objectives of using the LCA

varied between the publications, but mainly it is used for assessing the system and to identify the improvement possibilities and in some cases for developing sustainability indicators.

Mario et al. (2001), Rihon et al. (2002), Sven et al. (2004), and Teng (2006) used the LCA for assessing the environmental impacts of the urban water system in Bologna city, hydrographic basin of "La Vesdre" in Belgium, Sydney City, and the Netherlands respectively. The former two studies assessed only the current situation in order to identify the most critical processes within the system, while the third one used the assessment of the current situation as a basis for proposing scenarios for improving the system. Unlike the other three publications, Teng (2006) assessed the impacts of the system with respect to the climate change only.

The main driving force of the impacts resulted from the urban water system differed in the four publications. Mario et al. (2001) and Sven et al. (2004) said that in general the energy consumption is the driving force behind most of the impacts. In contrast, Teng (2006) found out that the main environmental impacts are from use of chemicals; however Mario et al. (2001) demonstrated that chemicals use impact is in general low but not irrelevant, this contrast between Teng (2006) and Mario et al. (2001) may be because the study of the former focused on the climate change only. The results of Rihon et al. (2002) study revealed that the wastewater treatment plants have the most significant impacts within the urban water system, moreover in the wastewater treatment plant the most significant impacts are due to the secondary and sludge treatment, on the other hand, Mario et al. (2001) and Sven et al. (2004) agreed that the wastewater treatment plants have significant impacts only in the eutrophication and aquatic ecotoxicity.

Due to the different results of the four studies, the ways suggested for decreasing the environmental impacts by the urban water system also varied between them. Mario et al. (2001) suggested that the environmental performance can be enhanced by energy efficiency, energy generation, and energy recovery, and Sven et al. (2004) added to them optimizing design and operation of pumping devices. Teng (2006) said that the use of chemicals needs more attention. Rihon et al. (2002) suggested that the use of sludge as fertilizer and the better management of the wastewater treatment plants can be good options for decreasing the environmental impacts of the urban water system, Mario et al. (2001) also noted that the management of the wastewater treatment plants can affect significantly on the eutrophication problems.

It is important to be emphasized that Sven et al. (2004) concluded that the cradle to grave approach is useful to assess the financial, social, and environmental issues, which are all necessary when making decision about the future of the urban water systems, in the same context, Teng (2006) suggested that in the future a comprehensive study on the water treatment in a pilot area is recommended to take into account the environmental, economic, technical, and social aspects.

The LCA was used also by some authors for developing sustainability indicators for the urban water system. Lundin (2000) discussed the use of LCA to develop sustainable development indicators for urban water systems. The study based on theoretical model represents the different components of any urban water system. In the same study, a frame work of a simplified LCA is suggested; this can be done by revealing the parameters that are most disturbing or typical for the examined sector or product group. The main idea of this framework is to avoid performing complete LCA, but instead to identify the most important processes. Lundin et al. (2002) used LCA as an analytical basis for selecting environmental sustainability indicators (ESI) for urban water systems. The study presented iterative procedures for the selection of the indicators. The iterative procedures contain the following steps: specifying the overall purpose, defining system boundaries (temporal, spatial, and LCA boundaries), developing framework of ESI, selecting appropriate ESI, data collection, and evaluation of the framework. Two case studies are used for the demonstration of the framework (Goteborg, Sweden; King William's Town, South Africa).

2.2.2 Studies carried out on part of the urban water system

2.2.2.1 Water treatment

In the field of water treatment the LCA is used mainly in order to compare between treatment technologies on environmental basis and also for comparing the water sources options. In addition to LCA, life cycle costing (LCC) was used also in this field for adding the economical dimension to the environmental one.

Mohapatra et al. (2002), Friedrich et al. (2002), and Barrios (2004) used LCA for comparing water treatment technologies; the rearmost used also the LCC. Mohapatra et al. (2002) assessed the environmental impacts of Leiduin water treatment plant (Amsterdam water supply Company). The study assessed the impacts of the current line and two alternatives treatment schemes for the capacity expansion using reverse osmosis. Friedrich et al. (2002) compared two water treatment technologies for production of potable water in South Africa; one based on coagulation and one based on membrane filtration. Barrios (2004) assessed the environmental and financial impacts from the pre-treatment of raw water at the Loenderveen and the treatment at the Weesperkarspel plants with the aim of identifying the operational conditions with the highest potential for impacts reduction at both facilities.

The results of the three studies showed that the most important process to which most of the environmental burdens for producing potable water are traced is the energy use, but Barrios (2004) added to the energy use the chemical use which was the dominant cause of environmental impacts in his study. Mohapatra et al. (2002) specified the most important contributors to the impacts which are: softening and the granular activated carbon process, Barrios (2004) mentioned the same processes as the main sources of not only environmental burdens but also of financial burdens and he added also the coagulation as one of the important processes. The results of Mohapatra et al. (2002) study showed that impact reduction up to 73% may be achieved by the use of 100% green energy, the use of an alternative chemical [Na_2CO_3 in place of NaOH] in the softening process and doubling the carbon run time.

The above three studies compared two technologies for the same water source, in another study carried out by Jennifer et al. (2005) more than one source of water are compared. Jennifer et al. (2005) compared the environmental burdens of three options of water supply; imported, desalinated, and recycled water (recycled water will not be used in drinking purpose but it will decrease the stress on the potable water). Models have been developed to compare the three options. Emissions were assigned to three water supply phases: supply, treatment, and distribution. The study used also a tool called economic input-output analysis-based LCA (EIO-LCA) to incorporate the financial dimension to the environmental one. The main conclusion of the study was that the recycled water is more environmentally benign than desalination, while the desalination has the most significant impacts due to the high energy consumption. This result is consistent with the results of the former three studies where the energy use was the major factor that caused the environmental impacts of the assessed systems.

Unlike the above studies, the study done by Landu et al. (2006) focused on the water use in the industrial sector; moreover the extraction of the water was added to the other aspects related to resource use and emissions. The study assessed the environmental life cycles of potable water supply systems for industrial usage in South Africa to identify key environmental aspects that should be considered where water is used in the manufacturing sector. Based on the interpretation of the results it was concluded that the actual extraction of the water from the ambient environment is in fact the most important consideration, moreover the water quality is very important due to the high energy use related to improving the quality (i.e. treatment) but it is of less importance.

2.2.2.2 Wastewater treatment

The assessment of the environmental impacts that may result due to the change from centralized wastewater treatment system to decentralized one was one of the important issues that studied by some publications by the aid of the LCA. Two studies undertaken by Tillman et al. (1998) and Lassaux et al. (2001) are focused on this issue (decentralization of wastewater treatment). Tillman et al. (1998) carried out the study on existing systems in Hamburgsund and Bergsjön (Sweden). The study proposed two alternatives for the decentralized system, in the first alternative existing piping in the areas would be used, but with local treatment consisting of pre-treatment, digestion or drying of solid fractions and treatment of liquid fractions in sand filter beds, in the other alternative, it was proposed that urine, faeces and grey water would separately be conducted out of the buildings. The study done by Lassaux et al. (2001) used only theoretical model for the comparison between the centralized and decentralized systems for the treatment of the same amount of wastewater.

The two studies had the same conclusion that the decentralized system had lower impacts than the centrlized one, Lassaux et al. (2001) explained that with the fact that the length of the sewerage system is smaller in the case of decentralized plants. Tillman et al. (1998) concluded that the separation of faeces and urine can decrease the environmental impacts of

the wastewater treatment significantly, it was also noted by the study that the use of the fossil fuel (mainly in electricity generation) is the major reason of the environmental impacts caused by the wastewater treatment plants.

Some publications used the LCA for the evaluation of the technologies that are used in the wastewater treatment in order to identify the hot spots in each of these technologies to enable the identification of the improvement options. Almudena et al. (2004) evaluated the potential environmental impacts associated with a municipal wastewater treatment plant. Among all the impact categories studied, the eutrophication (due to the nutrients in the effluent) and terrestrial toxicity (due to pathogens and heavy metals in the sludge) were reported to be the most significant impacts, that led to the conclusion that there's need for tertiary treatment and proper management of the sludge. The study also differentiated between the dry season and wet season in the analysis, but no significant difference has been found. Omar et al. (2005) assessed the technology of granular activated carbon (GAC) which is widely used in the industrial wastewater treatment for controlling the emissions of volatile organic compounds. The GAC for treating two different chemical streams was assessed. The study also examined the hypothesis that the higher the pollution abatement the lower the environmental impacts from the wastewater treatment technologies, the results of the study revealed that this is not true. Also the study concluded that some wastewater technologies have higher environmental impacts than the untreated sewer.

The choice of the proper way of dealing with wastewater on environmental basis is one of the applications of LCA. Hazem et al. (2001) applied LCA to assess the environmental impacts of six selected investment approaches (developments) which all tackle the problem of sanitary waste being discharged to the environment, the six options categorized into three main categories (end of pipe solution, habit change, and spill reduction) . The life cycle of the components and solids for each option was individually assessed, identifying: the materials used, energy consumed and releases to the environment, including transportation, recycling and re-use. The assessment excludes the (combined) sewerage system structure itself as that is constructed primarily to handle liquid waste (sewage) and also storm drainage, rather than the sanitary solids as such. Of all the options considered for the handling of sanitary waste, LCA results showed that encouragement to the public to stop flushing this waste into the sewer system is the option which has the least environmental impact, whilst screening at the end of the pipe has the most significant impact.

2.2.2.3 Sewage sludge management

One of the hot topics related to the wastewater treatment is the sewage sludge management, in this context the LCA was used for assessing the different options of sludge management. Dennison et al. (1998) studied the management of the sludge resulting from 15 wastewater treatment plants operated by Thames water utilities Ltd. in the UK. The study proposed five management regimes for centralizing sludge treatment and disposal, the five regimes are a combination between centralization, composting, and digestion. The study showed that the option of complete centralization and composting prior to disposal exerts the least environmental impacts. Almudena et al. (2005) carried out an assessment by using LCA to

examine different alternatives of sewage sludge post-treatment: agricultural use of digested sludge, incineration and pyrolysis. The study couldn't find the best option as no alternative has the most favourable results for all the impact categories quantified. However, the study concluded that the land application of digested sludge is an acceptable option; probably not the best, but at least a good one, moreover it was noted that the sludge management strategy is site dependent.

2.2.3 General comments on the previous studies

Most of the studies that have been reviewed above showed that the environmental impacts were mainly due to the energy use while two of the studies (Barrios, 2004 ; Teng, 2006) concluded that the chemical use was the major driving force for the environmental impacts (Teng studied only the impacts on the climate change). So, it was reported that to further improve the environmental performances of the water cycle it is necessary to reduce the energy consumption, optimizing design and operation of pumping devices (Mario et al., 2001), and also by demand management, energy generation, and energy recovery (Sven et al., 2004).

It was also concluded by Rihon (2002) that the environmental impacts of the urban water systems are mainly due to the wastewater treatment and the pumping. So, more attention must be paid to the wastewater treatment especially for the secondary and sludge treatments which can lead to the eutrophication and terrestrial toxicity; both considered as the main impacts of wastewater treatment plants as reported by Almudena et al. (2004).

It has to be emphasized that all the studies that have assessed the whole life cycle of the urban water system considered only the environmental impacts, but some of them (Sven et al.,2004; Teng, 2006) recommended that social and financial aspects have to be considered. However, some of the studies that assessed part of the system considered both the environmental aspects and the financial aspects such as Barrios (2004), and Jennifer et al. (2005).

3 Methodology and Basic Data

In this chapter the materials and the methods that have been used in this research will be introduced. The chapter will include also the inventory analysis of the different compartments of the system, and the mass balance of the system. Moreover the software and the method used in the assessment will be presented.

3.1 Inventory analysis

The data required for achieving the objectives of this research have been collected from the available sources. The data for drinking water system is collected from Alexandria's drinking water company and through field visits to the water treatment plants (where possible) and with direct contact with the operators of the system.

The data of the wastewater and sanitation system have been collected from the operators of the wastewater treatment plants and from the information centre of Alexandria's sanitation drainage company. Also some visits have been made to the wastewater treatment plants to collect the data.

Some of the data that used in this research was reasonably assumed due to the unavailability of this data; the assumptions will be mentioned in the related sections. In addition, data form literature has been used where needed in the research. The data from literature has been chosen from sources that have similar conditions to those in Alexandria.

3.1.1 Mass balance of treatment processes

3.1.1.1 Water balance

The total amount of drinking water produced by the water treatment plants in Alexandria city is about 2.3 Mm^3/d, it is assumed that 35 % of this amount is losses in the distribution network (average value for the middle east (Trifunovic, 2006)) so the amount of water which really used by the different users (domestic and industrial use) is about 1.51 Mm^3/d. It is also being assumed that 70% only of all the water that reaches the consumers is turned into wastewater (Adewumi, 2006), so the amount of wastewater that has to go to the sewerage network is about 1.06 Mm^3 / d.

The total amount of wastewater that is treated in the WWTPs is about 0.83 Mm^3/d which is discharged to Mariout Lake then to the sea or directly to the sea through the drains, in addition to that there's about 0.029 M m^3/d of untreated wastewater which is discharged to the drains and then to the sea. Assuming that there's a 15% losses in the sewerage network, so the actual amount that is collected by the sewerage network is about 1.01 Mm^3/d. Moreover, 0.05 Mm^3/d of industrial wastewater is discharged into Lake Mariout (Masaoud, 2002).

Subtracting the actual amount of wastewater that is been collected in the sewerage network and the industrial wastewater from the amount that should be discharged to the sewerage network, one can find that there is amount of wastewater of about 5829.31 m^3/d that doesn't been collected in the system. This amount of water could be some private sanitation (septic tanks) or even illegal discharge of domestic wastewater to the water streams. Figure 3.1 shows schematic for the water balance, where the percentages in the diagram are the calculated with respect to the total amount of drinking water.

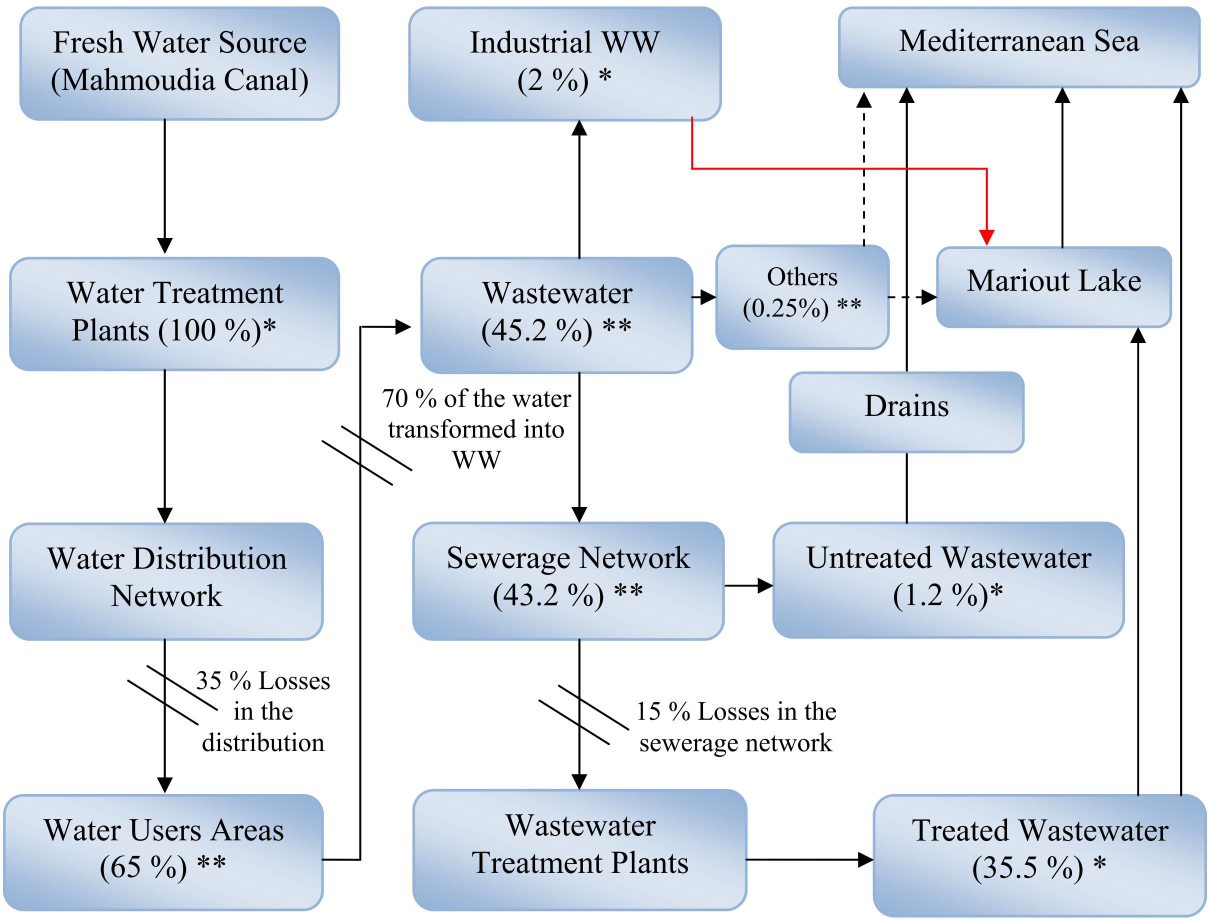

Figure 3.1: Water balance of Alexandria's urban water system.

<u>Note</u>: * refers to collected data, and ** refers to calculated data

3.1.1.2 Nutrients balance

The average concentration of phosphorous and nitrogen is calculated by dividing the total load (summation of the loads of all the WWTPs) by the total volume of the wastewater in the four WWTPs (0.043 mg/l for untreated wastewater, and 0.038 mg/l for treated wastewater). And to calculate the figures in the diagram below; the average concentration is multiplied by the amounts of water which have been calculated in the water balance calculations. The total amount of nutrients (phosphorous and nitrogen) that is produced out of the system is about 45.2 tons per day (38.15 tons of nitrogen and 7.05 tons of phosphorous). Figure 3.2 shows

schematic for the nutrients balance, the percentages in the diagram representing the contribution of each part of the wastewater from the total nutrients.

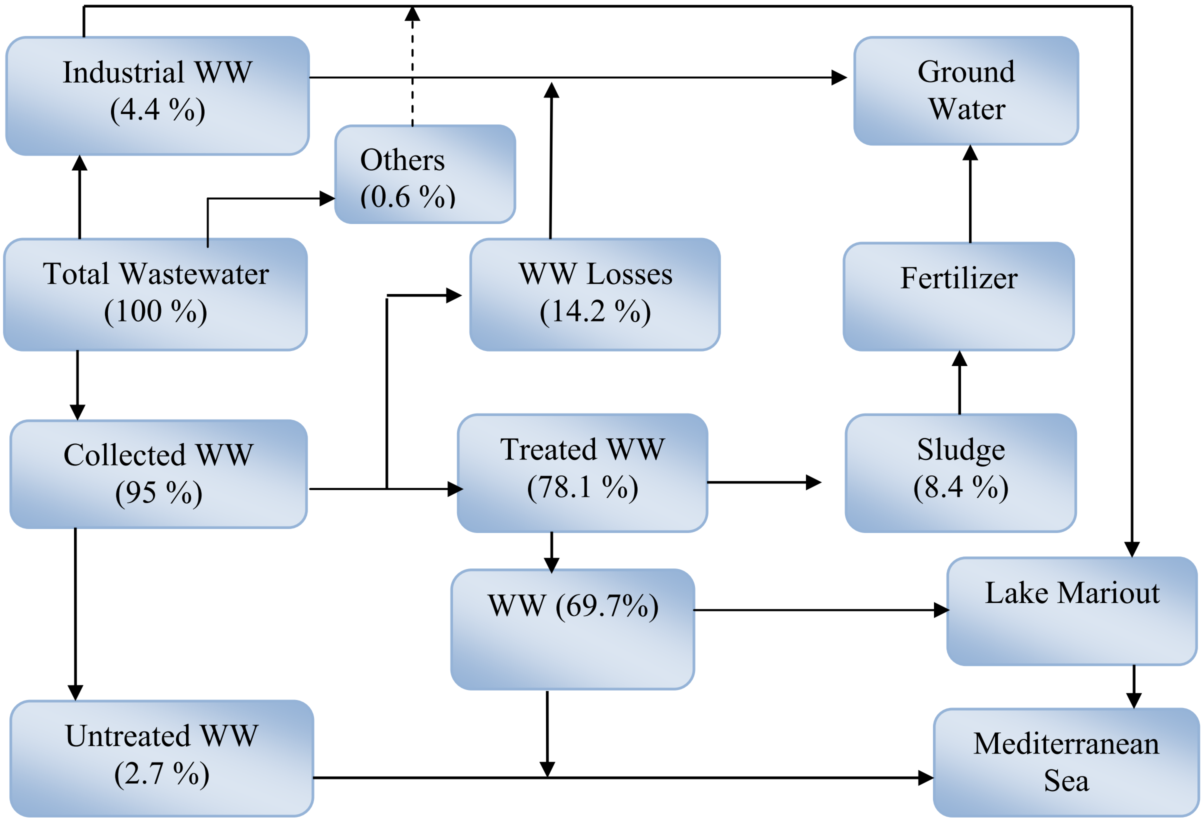

Figure 3.2: Nutrients balance of Alexandria's urban water system.

Note: WW refers to wastewater

3.1.2 Data collection for water treatment

The data for water treatment was collected from Alexandria Drinking Water Company. The data is presented in Table 3.1 for the seven water treatment plants and for the main treatment units of each treatment plant. The data in Table 3.1 is the normalized data where all the values are per cubic meter of clean water produced from each plant. The data in the table contains transportation of chemicals which assumed to be transported from Cairo (250 km from Alexandria).

Table 3.1: Normalized data of the water treatment plants.

		Bab Sharky	El-Seiouf	El-Manshia	Forn Al-Garia
Raw water Pumping	Unit				
Volume of water	m^3/d	407457	755922.5	596271.533	42378.5
Electricity for pumping	kwh/m^3	0.10497364	0.1049305	0.13074732	0
Clarification					
Chlorine	kg/m^3	0.00410744	0.00192788	0.00363937	0.004328466

		Bab Sharky	El-Seiouf	El-Manshia	Forn Al-Garia
Aluminium sulphate	kg/m^3	0.03644773	0.02903738	0.033659878	0.047017331
Electricity	kwh/m^3	0.02233482	0.02232564	0.02781858	0.013859991
Sludge	kg/m^3	0.0128619	0.01280474	0.01643465	0.011632564
Transportation of Cl_2	tkm/m^3	0.00102686	0.00048197	0.00090984	0.001082116
Transportation of Al_2So_3	tkm/m^3	0.00911193	0.00725935	0.00841497	0.011754333
Rapid sand filtration					
Back wash water	m^3/m^3	0.0135906	0.024154924	0.014753962	0.009953796
Sludge	kg/m^3	0.0028582	0.003372676	0.002543798	0.002873654
Clean Water Pumping					
Volume of water	m^3/d	401012.6	738289.7667	585266.5333	41793.1
Chlorine	kg/m^3	0.0026089	0.002478702	0.003195125	0.001610314
Electricity for pumping	kwh/m^3	0.09603972	0.096000243	0.11961989	0.101639936
Transportation of Cl_2	tkm/m^3	0.00065222	0.000619675	0.000798781	0.000402578

Table 3.1 (cont.): Normalized data of the water treatment plants**.**

		El-Ma'amora	El-Nozha	Mariout
Raw water Pumping	Unit			
Volume of water	m^3/d	147753.7	104255.03	331437.9667
Electricity for pumping	kwh/ m^3	0.110608126	0	0.148471941
Clarification				
Chlorine	kg/ m^3	0.002223087	0.0041253	0.002861610
Aluminium sulphate	kg/ m^3	0.02006837	0.0199218	0.025672849
Electricity	kwh/m^3	0.023533644	0.0155567	0.031589775
Sludge	kg/ m^3	0.01386227	0.0132906	0.015632456
Transportation of Cl_2	tkm/m^3	0.000556	0.001031	0.000715
Transportation of Al_2So_3	tkm/m^3	0.005017	0.00498	0.006418
Rapid sand filtration				
Back wash water	m^3/ m^3	0.019765892	0.0278631	0.033455586
Sludge	kg/ m^3	0.00400148	0.0028010	0.002635421
Clean Water Pumping				
Volume of water	m3/d	144693.7	101448.37	316837.9667
Chlorine	kg/ m^3	0.003547724	0.0015499	0.001430805
Electricity for pumping	kwh/m^3	0.101194668	0.1140823	0.135836031
Transportation of Cl_2	tkm/m3	0.000887	0.000387	0.000358

3.1.3 Data collection for wastewater treatment

The data for wastewater treatment is collected from Alexandria Sanitation Drainage Company and from the wastewater treatment plants; in addition, data from Alemandu et al. (2005) is used for modelling the impacts of the sludge composting and land application. The data is shown in the following tables (3.2); the data is categorized depending on the emissions resulting from each plant and from the composting and land application of sludge. All the

data shown below is expressed per cubic meter of wastewater except the data of composting and land application of sludge which is per one ton dry matter of sludge.

Note: The air borne emissions are calculated based on the following equation:

$$C_6H_{12}O_6 + 6\ O_2 \longrightarrow 6CO_2 + 6H_2O \qquad \textbf{Equation 3.1}$$

Where it is been assumed that all the COD is in the form of Glucose.

Table 3.2: Normalized data for East WWTP.

Item	Value	Item	Value
Influent Water borne pollutants	(Kg/m3)	**Effluent Water borne pollutants**	(Kg/m3)
T.S.S	0.22804	T.S.S	0.11182
BOD	0.17580	BOD	0.12907
COD	0.48293	COD	0.32828
N, total	0.03840	N, total	0.03530
P, total	0.02620	P, total	0.02300
Energy consumption (kWh/m3):		**Air borne Emissions (kg/m^3):**	
Process energy	0.01090	Carbon dioxide(CO_2)	0.14969
Pumping energy	0	**Solid Emissions (kg/m^3)**	
Total energy	0.01090	Screenings	0.00012
Transportation (tkm/m^3)		Grits	0.00081
Transportation of sludge	0.00349	Sludge	0.11623
		Total (Screenings+Grits+Sludge)	0.11716

Table 3.3: Normalized data for west WWTP.

Item	Value	Item	Value
Influent Water borne pollutants	(Kg/m3)	**Effluent Water borne pollutants**	(Kg/m3)
T.S.S	0.95172	T.S.S	0.14257
BOD	0.46903	BOD	0.15483
COD	1.15442	COD	0.34345
N, total	0.01150	N, total	0.00923
P, total	0.00823	P, total	0.00780
Energy consumption (kWh/m3):		**Air borne Emissions (kg/m^3):**	
Process energy	0.01952	Carbon dioxide(CO_2)	0.78494
Pumping energy	0.06826	**Polymers (kg/m^3)**	0.00142
Dewatering energy	0.04998	**Solid Emissions (kg/m^3)**	
Total energy	0.13776	Screenings	0.00034
Transportation (tkm/m^3)		Grits	0.00138
Transportation of sludge	0.02539	Sludge	0.84616
Transportation of polymers	0.00035	Total (Screenings+Grits+Sludge)	0.86188

Table 3.4: Normalized data for Eskan Mubark WWTP.

Item	Value	Item	Value
Influent Water borne pollutants	(Kg/m3)	**Effluent Water borne pollutants**	(Kg/m3)
T.S.S	0.216	T.S.S	0.013
BOD	0.228	BOD	0.016
COD	0.266	COD	0.024
N, total	0.0014	N, total	0.0009
P, total	0.0089	P, total	0.0080
Energy consumption (kWh/m3):		**Air borne Emissions (kg/m3):**	
Process energy	0.08399	Carbon dioxide(CO_2)	0.23401
Pumping energy	0	**Polymers (kg/m^3)**	0.00133
Dewatering energy	0.04732	**Solid Emissions (kg/m^3)**	
Total energy	0.13131	Screenings	0.00016
Transportation (tkm/m^3)		Grits	0.00077
Transportation of sludge	0.00610	Sludge	0.20219
Transportation of polymers	0.00033	Total (Screenings+Grits+Sludge)	0.20301

Table 3.5: Normalized data for Hanoville WWTP.

Item	Value	Item	Value
Influent Water borne pollutants	(Kg/m3)	**Effluent Water borne pollutants**	(Kg/m3)
T.S.S	0.19	T.S.S	0.009
BOD	0.23	BOD	0.01
COD	0.15	COD	0.02
N, total	0.00162	N, total	0.0009
P, total	0.00834	P, total	0.0071
Energy consumption (kWh/m3):		**Air borne Emissions (kg/m^3):**	
Process energy	0.08784	Carbon dioxide(CO_2)	0.12679
Pumping energy	0	**Polymers (kg/m^3)**	0.00139
Dewatering energy	0.04853	**Solid Emissions**	
Total energy	0.13636	Screenings	0.00023
Transportation (tkm/m^3)		Grits	0.00065
Transportation of sludge	0.00543	Sludge	0.18153
Transportation of polymers	0.00035	Total (Screenings+Grits+Sludge)	0.18224

Table 3.6: Normalized data for Composting and land application of sludge (Alemandu et.al, 2005).

Item	Value	Item	Value
Energy consumption (kWh/t)		**Emissions to soil (kg/t):**	
Electricity	58.5	Cr	0.08
Diesel	0.73	Cu	0.19
Air borne Emissions (kg/t):		Pb	0.33
CH4	3.18	Zn	1.51
Avoided Products (kg/t)		**Avoided Products (kg/t)**	
N-Fertilizer	17.87	P-Fertilizer	14.32

3.1.4 Data collection for the energy use of water and wastewater transportation

For transporting the wastewater from the use areas to the treatment plants or to drains ends to the treatment plants or to the sea, about 39 pump stations are used to overcome the problems of the levels difference in the different places. The data of electricity consumption of the pump stations was collected from Alexandria's Sanitation Drainage Company.

The drinking water network also has 43 booster pumps to increase the water pressure in addition to private pumps used by the people. Unfortunately there's no data about the energy use in these pumps, so the equations of fluid mechanics will be used to calculate the energy in these pumps. The energy consumption can be expressed using the following equation (Trifunovic, 1999):

$$E = \rho * g * Q * H * T / \eta \quad \textbf{Equation 3.2}$$

Where 'ρ' is the water density, 'g' is the gravitational acceleration, 'Q' is the total pumped water, 'H' is the total head of the pump, 'T' is the working hours, and 'η' is the pumping efficiency.

In order to calculate the energy of the booster pumps, it was assumed that halve of the amount of water that is produced by the water treatment plants will be re-pumped by the booster pumps with a head of about 28 m (the calculated average head of the clean water pumps in the water treatment plants). For the private pumps the amount of water is calculated for the domestic use only (200 l/d) and the head is about 21 m (height of a 7 flours building).Table 3.7 shows the energy consumption for water and wastewater transportation.

Table 3.7: Energy consumption of water and wastewater transportation.

	Volume of water pumped (m3/day)	Energy use (kwh/m3)	Total energy use (kwh/day)
Water transportation	1,890,000	0.082787	156,467.4038
Wastewater transportation	1,174,050	0.06825925	81,937.733

3.2 Environmental impact assessment

In this section the procedures used in assessing the environmental impacts of the different components of the system will be discussed in addition to the software and the method used in the assessment.

3.2.1 The software used in the life cycle assessment

The software SimaPro is used in this research for conducting LCA for Alexandria's urban water system and its components. SimaPro software (System for Integrated Environmental Assessment of Products) is one of the most widely used software in carrying out LCA studies,

the standard ISO methodology of carrying out LCA studies is already used by SimaPro, and following are the procedures of the impact assessment process:

1. Goal and Scope definition: The goal and scope of this research are mentioned in chapter 1. In addition the functional unit is cubic meter of water and wastewater, so all the data have been expressed per cubic meter of water or wastewater.

2. Construction of the model: The model in SimaPro is divided into the main processes in each system in addition to the waste scenario or the disposal scenario. The processes are merged together in what is called the assembly, and then the life cycle is the assembly and the waste or disposal scenario. The inputs and the outputs of each process are added based on the inventory analysis. All the processes can be linked together and can be linked to the processes in the data base of the software.

3. Checking the model: SimaPro can show schematically all the processes in the model and the links between the processes, that can reveal any problems or mistakes in the construction of the model.

4. Analysing the model: In order to analyze the model the method of the assessment has to be chosen first where the SimaPro has several methods that can be used in the calculations. After choosing the method of the assessment the software carries out the classification, characterisation, normalization and weighing processes.

3.2.2 The system analysis

Alexandria's urban water system as have been described earlier has four main compartments which are the water treatment plants, the wastewater treatment plants, the water transportation, and the wastewater transportation. In addition, the untreated wastewater (domestic and industrial) were considered as one of the system compartments. The characteristics of the untreated wastewater were considered as the average of the influent characteristics of all the wastewater treatment plants.

The losses in the sewerage network which represents about 6.5 % of the total amount of the produced drinking water were not considered in this research because it is fate is not very clear, while the losses in the distribution network were already calculated as a part of the water treatment plants because its impact is only in the treatment process. Figure 3.3 shows the model of Alexandria's urban water system, while the models of each subsystem are shown in Annex E.

On the other hand, the pre-treatment of the industrial wastewater by the industries were not taken into consideration, but the impact of the industrial wastewater was considered to start from the point of discharge of the industrial wastewater either to the sewerage network or to the water bodies.

3.2.3 The assessment method

The assessment method used in this research is Eco-Indicator 99 which is damage oriented method (the damage that caused by a product or a system on the environment). The following impact categories were taken into account:

- Carcinogenic effects
- Respiratory effects caused by organic substances
- Respiratory effects caused by inorganic substances
- Climate change
- Eco-toxic emissions
- Acidification and eutrophication
- Extraction of minerals
- Extraction of fossil fuels

Unfortunately, the method has shortcoming related to the impact of nutrients and COD with respect to the eutrophication, this shortcoming is that the method gives no damage factors to the nutrients and COD with respect to eutrophication. So, for better adaptation for the method, characterisation factor from Eco-invent report No.3 (2004) for total nitrogen was used and based on the characterisation factors from Eco-indicator 95 the characterisation factors of phosphorous and COD is calculated. The characterisation factors for nitrogen, phosphorous, and COD are presented in Table3.8 (More details about the calculations of the characterization factors are presented in Annex B)

Although, the characterisation factors are based mainly on rough assumptions but it was decided that this is better than ignoring these emissions at all. Description of Eco-Indicator 99 is introduced in annex A.

Table 3.8 : Characterisation factors of N, P, COD**.**

Substance	Eco-indicator 95 characterisation factors	Calculated Characterisation factor (PDF*m^2*yr / kg)
COD	0.022 kg PO^4	0.98
N	0.42 kg PO^4	18.8
P	3.06 kg PO^4	136.97

<u>**Note**</u>: PDF refers to potentially disappeared fraction of species.

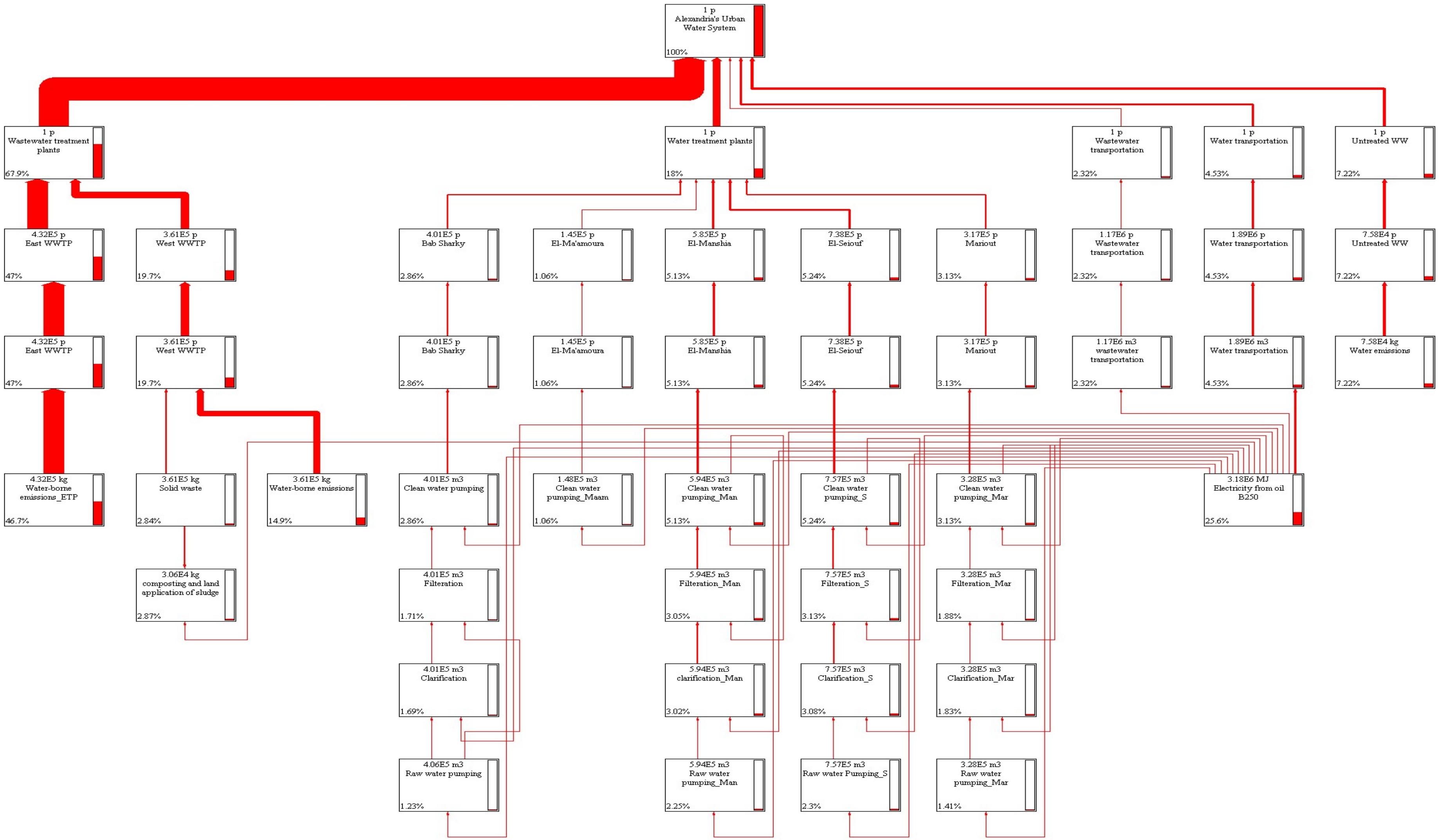

Figure 3.3: SimaPro model of Alexandria's urban water system (cut off 1 %).

3.2.4 Sensitivity analysis

Sensitivity is the influence that one parameter (the independent variable) has on the value of another (the dependent variable), both of which may be either continuous or discrete. Independent variables in LCA may be input parameter value (continuous), system boundary, allocation rule, model choice, or process choice (all discrete). Dependent variables may be output parameter values (continuous) or priorities between alternatives in a comparative study (discrete). (Björklund, 2002)

The sensitivity analysis is a way for identifying the critical parameters in the system; those are the parameters with higher sensitivity. The system parameters can be ranked according to their sensitivity values, a higher sensitivity value means that a slight change in the parameter value will result in a high change in the impact of the system, so more attention have to be paid for those parameters.

Monte Carlo simulation is considered the most famous technique in calculating the sensitivity. Monte Carlo simulation is a very simple technique depends on repeating the calculations many times, each time choosing a different (randomly chosen) value for an input parameter.

As citied by Barrios (2004), the absolute sensitivity is defined as:

$$Sa = \frac{(Rs - Rn)}{(Ps - Pn)} = \frac{\Delta R}{\Delta P} \qquad \text{Equation 3.3}$$

Where: 'Sa' is absolute sensitivity; 'Rs' and 'Rn' are the simulated and nominal results of the model (impact or cost), respectively; 'Ps' and 'Pn' are the simulated and nominal input parameters of the model, respectively.

Defining the relative sensitivity 'Sr 'as the ratio of the change rate in the output (R) to the change rate in the inputs (parameters P), a dimensionless value of sensitivity is obtained (Barrios,

$$Sr = \left(\frac{\Delta R / R}{\Delta P / P} \right) \times 100 \qquad \text{Equation 3.4}$$

3.3 Scenario analysis for the improvement potentials

The assessment of the environmental impact of the system and the sensitivity analysis could reveal the possible ways of improving the system. So, based on the impact assessment and the sensitivity analysis scenario analysis of the possible ways for improving the system will be carried out. The proposed scenarios will be analysed using the same way that was mentioned in the previous section.

Based on the analysis of the proposed scenarios the better scenario (or scenarios) will be chosen. In addition, the recommended solutions for improving the system will be identified.

4 Results of the Impact Assessment

In this chapter the environmental impacts of the different compartments of the system will be presented. In addition, the total impact of the system and the contribution of each compartment of the system will be also introduced. The chapter will include also the proposed scenarios for improving the total performance of the system and its sub-components.

4.1 Environmental impacts of Alexandria's urban water system

In this section the impacts of each compartment of the system will be introduced, and then the contribution of each compartment in the total impact of the system will be presented.

4.1.1 Environmental impacts of water treatment plants

Table 4.1 shows the environmental impacts of the water treatment plants (eco-points/m^3), the impacts in the table are per cubic meter of clean water produced by the plants. All the plants showed very similar values of the impact per cubic meter; the only exceptions were Forn El-Garya and El-Nozh. The impact of El-Manshia treatment plant was the highest impact per cubic meter (0.026 eco-points /m^3).

Table 4.1: Environmental impact of the water treatment plants (eco-points/m^3).

Impact category	Unit	Bab Sharky	El-Ma'amoura	El-Manshia	El-Nozha	El-Seiouf	Forn El-Garya	Mariout
Carcinogens	Pt/m^3	0.000172	0.000173	0.000209	0.000104	0.000169	0.000106	0.000232
Resp. organics	Pt/m^3	1.35E-05	1.41E-05	1.67E-05	8.18E-06	1.34E-05	7.61E-06	1.88E-05
Resp. inorganics	Pt/m^3	0.00408	0.00397	0.00486	0.00246	0.00394	0.00273	0.00526
Climate change	Pt/m^3	0.000919	0.000951	0.00113	0.000554	0.000914	0.000527	0.00127
Radiation	Pt/m^3	0	0	0	0	0	0	0
Ozone layer	Pt/m^3	3.75E-06	3.96E-06	4.68E-06	2.23E-06	3.79E-06	2.03E-06	5.37E-06
Ecotoxicity	Pt/m^3	0.000767	0.000805	0.000954	0.000455	0.000774	0.00042	0.00109
Acidification/ Eutrophication	Pt/m^3	0.000466	0.000457	0.000556	0.000282	0.00045	0.000308	0.000603
Land use	Pt/m^3	0	0	0	0	0	0	0
Minerals	Pt/m^3	4.52E-09	3.96E-09	4.67E-09	3.93E-09	3.04E-09	4.04E-09	2.99E-09
Fossil fuels	Pt/m^3	0.0148	0.0156	0.0184	0.00885	0.0149	0.00812	0.021
Total	Pt/m^3	0.0212	0.0219	0.0261	0.0127	0.0212	0.0122	0.0295

Due to the different water production capacity of the water treatment plants, the total impact of the plants differs considerably among them as shown in Figure 4.1. Based on the total impact El-Seiouf plant had the highest total impact due to its high water production rate. El-Manshia and El-Seiouf plants contribute by about 57.6 % of the total impact of the water treatment plants, and by adding to them Bab Sharky and Mariout the impact of the four plants will be about 91 % of the total impact of the water treatment plants.

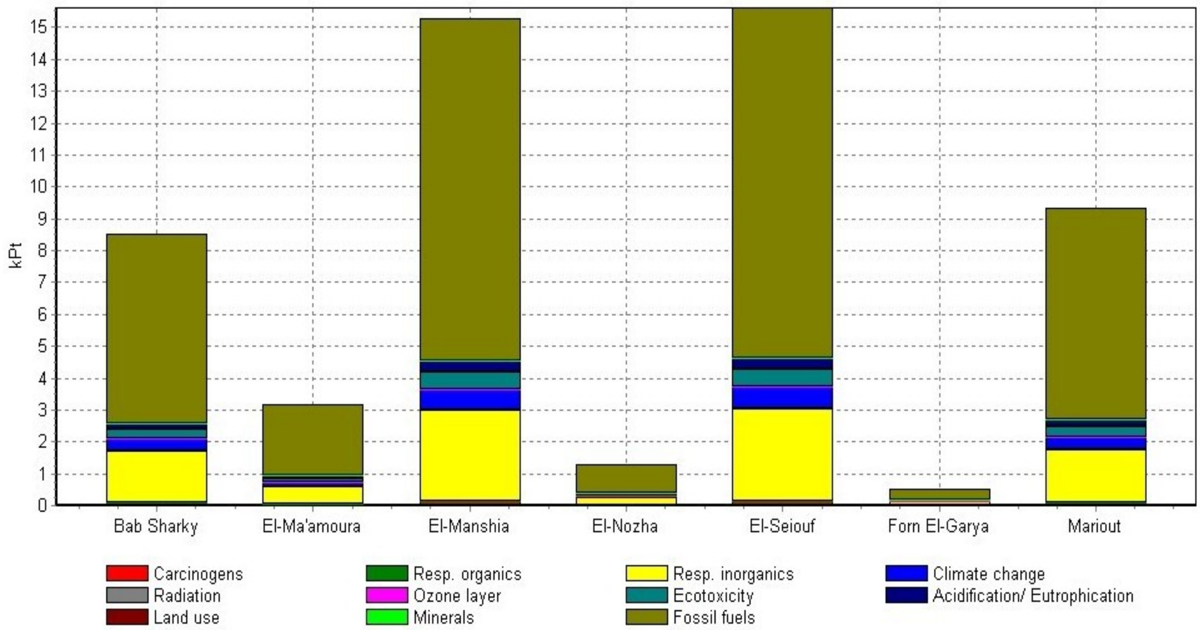

Figure 4.1: Total impact of the water treatment plants (eco-points)**.**

4.1.2 Environmental impact of wastewater treatment plants

The environmental impact of the four wastewater treatment plants showed high fluctuation, the highest impact was the impact of the east WWTP which was about 0.32 eco-points / m^3. Although the east WWTP and the west WWTP use the same operation system but the impact of the west WWTP (0.16 eco-points / m^3) was almost half the impact of the west WWTP. The two secondary WWTPs had lower impacts, the impact of Hanoville WWTP and the impact of Eskan Mubark WWTP was 0.098 eco-points / m^3 and 0.112 eco-points / m^3 respectively. The impacts of the wastewater treatment plants per cubic meter of wastewater are shown in Table 4.2.

Table 4.2: Environmental impacts of the wastewater treatment plants (eco-points/m^3).

Impact category	Unit	East WWTP	Eskan Mubark WWTP	Hanoville WWTP	West WWTP
Carcinogens	Pt/m^3	0.00000719	0.00012	0.000115	9.44E-05
Resp. organics	Pt/m^3	0.000000651	0.0000101	7.85E-06	8.23E-06
Resp. inorganics	Pt/m^3	0.000165	0.00256	0.00209	0.00193
Climate change	Pt/m^3	0.00093	0.00206	0.00136	0.00515
Radiation	Pt/m^3	0	0	0	0

Impact category	Unit	East WWTP	Eskan Mubark WWTP	Hanoville WWTP	West WWTP
Ozone layer	Pt/m^3	0.000000182	0.00000296	2.28E-06	2.35E-06
Ecotoxicity	Pt/m^3	0.0000359	0.00637	0.0056	0.024
Acidification/ Eutrophication	Pt/m^3	0.323	0.089	0.0789	0.123
Land use	Pt/m^3	0	0.00000174	6.15E-05	1.74E-06
Minerals	Pt/m^3	0	2.16E-08	7.63E-07	2.16E-08
Fossil fuels	Pt/m^3	0.000707	0.0114	0.00978	0.00861
Total	Pt/m^3	0.324	0.112	0.098	0.163

The total impacts of the wastewater treatment plants are affected greatly by the capacity of each plant (as well as the case in the water treatment plants). The total impact of the east WWTP is the highest impact followed by the total impact of the west WWTP. The east WWTP and the west WWTP represents about 98% of the total impact of the wastewater treatment plants, while the impact of the two secondary WWTPs was about 2% of the total impact only. Figure 4.2 shows the total impact of the four WWTPs.

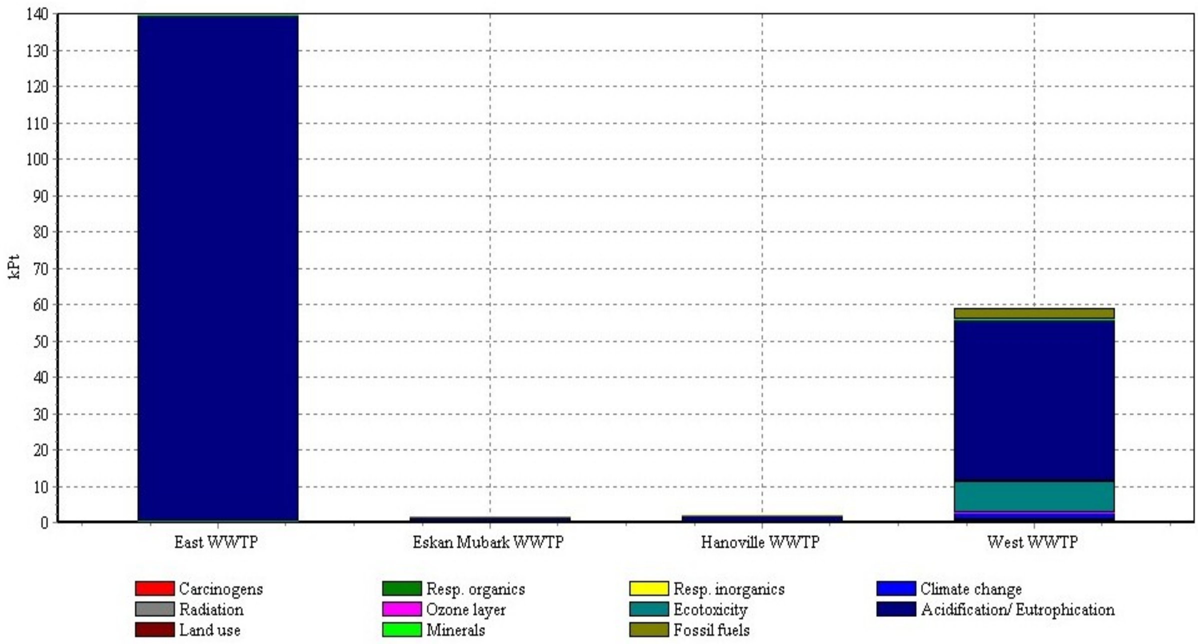

Figure 4.2: Total impact of the wastewater treatment plants (eco-points).

4.1.3 Environmental impacts of the untreated wastewater

The impact of the untreated wastewater is about 0.28 eco-points / m^3, and the total impact is about 2.15E4 eco-points. All the impact is in the category of eutrophication and acidification category and climate change category. The impacts of the untreated wastewater are shown in Table 4.3.

Table 4.3: Environmental impacts of the untreated wastewater (eco-points/m^3).

Impact category	Unit	Total
Carcinogens	Pt/m^3	0
Resp. organics	Pt/m^3	0
Resp. inorganics	Pt/m^3	0
Climate change	Pt/m^3	0.00123
Radiation	Pt/m^3	0
Ozone layer	Pt/m^3	0
Ecotoxicity	Pt/m^3	0
Acidification/ Eutrophication	Pt/m^3	0.283
Land use	Pt/m^3	0
Minerals	Pt/m^3	0
Fossil fuels	Pt/m^3	0
Total	Pt/m^3	0.284

4.1.4 Environmental impacts of transportation of water and wastewater

The impact of water transportation showed higher values with respect to all the impact categories than the impact of the wastewater transportation. The impact of the water transportation was about 0.007 eco-points / m^3, and its total impact was about 1.35E+4 eco-points. The impact of the wastewater transportation was about 0.006 eco-points / m^3, and its total impact was about 6.91E+3 eco-points. Most of the impact of the water and wastewater transportation (about 73% of the total impact) was in the category of fossil fuel. Table 4.4 shows the total impacts of the water and wastewater transportation.

Table 4.4: Total environmental impacts of the water and wastewater transportation (eco-points).

Impact category	Unit	Wastewater transportation	Water transportation
Carcinogens	Pt	52.4	102
Resp. organics	Pt	4.41	8.61
Resp. inorganics	Pt	1130	2210
Climate change	Pt	298	582
Radiation	Pt	0	0
Ozone layer	Pt	1.3	2.53
Ecotoxicity	Pt	263	513
Acidification/ Eutrophication	Pt	131	255
Land use	Pt	0	0
Minerals	Pt	0	0
Fossil fuels	Pt	5030	9830
Total	Pt	6910	13500

4.1.5 Contribution of each compartment to the total impact of the system

The assessment of Alexandria's urban water system showed that:

- The WWTPs represented about 67.8 % of the total impact of the system,
- The water treatment plants represented about 18 % of the total impact of the system,
- The water transportation represented about 4.5 % of the total impact of the system,
- The wastewater transportation represented about 2.3 % of the total impact of the system, and
- The untreated wastewater represented about 7.2 % of the total impact of the system.

The aforementioned results demonstrate that the WWTPs is the most problematic part in Alexandria's urban water system, that means that more attention have to be paid to the WWTPs. The total impacts of the compartments of the system are shown in Table 4.5.

Table 4.5: Total environmental impacts of the main compartments of Alexandria's urban water system (eco-points).

Impact category	Unit	Total	WWTPs	Water treatment plants	Wastewater transp.	Water transp.	Untreated WW
Carcinogens	Pt	626	41.2	430	52.4	102	0
Resp. organics	Pt	50.8	3.56	34.2	4.41	8.61	0
Resp. inorganics	Pt	14200	849	9990	1130	2210	0
Climate change	Pt	5620	2320	2330	298	582	93.3
Radiation	Pt	0	0	0	0	0	0
Ozone layer	Pt	14.5	1.02	9.63	1.3	2.53	0
Ecotoxicity	Pt	11600	8890	1960	263	513	0
Acidification/ Eutrophication	Pt	210000	187000	1140	131	255	21400
Land use	Pt	1.89	1.89	0	0	0	0
Minerals	Pt	0.0323	0.0234	0.00888	0	0	0
Fossil fuels	Pt	56500	3780	37900	5030	9830	0
Total	Pt	298000	202000	53700	6910	13500	21500
Total	%	100.00	67.79	18.02	2.32	4.53	7.21

The results presented above showed the total environmental impact by each compartment of the system which is mostly dependent on the amount of water in each compartment. But, the picture could by different in terms of the normalized impact (eco-points / m^3) of each compartment in the system.

In terms of the normalized impact the environmental impact of the untreated wastewater was much higher than the impact of the water treatment plants. The impact of untreated wastewater was about 0.28 eco-points / m^3, while the total impact of the seven water treatment plants was 0.15 eco-points / m^3, and the average impact of the water treatment plants was only 0.02 eco-points / m^3.

In the same basis of the normalized impact the impact of the untreated wastewater is higher than the average impact of the wastewater treatment which is 0.17 eco-points / m^3. Also it is possible to calculate the normalized impact of the whole system, but this will depend on the pathways of the water. One pathway could water treatment, water transportation, wastewater treatment, and wastewater transportation, this pathway resulted an average impact of about 0.21 eco-points / m^3. Another pathway is when the wastewater ends up in the water bodies without treatment; the average impact of this pathway is about 0.32 eco-points / m^3. Figure 4.3 shows the normalized data of the main compartments of the system

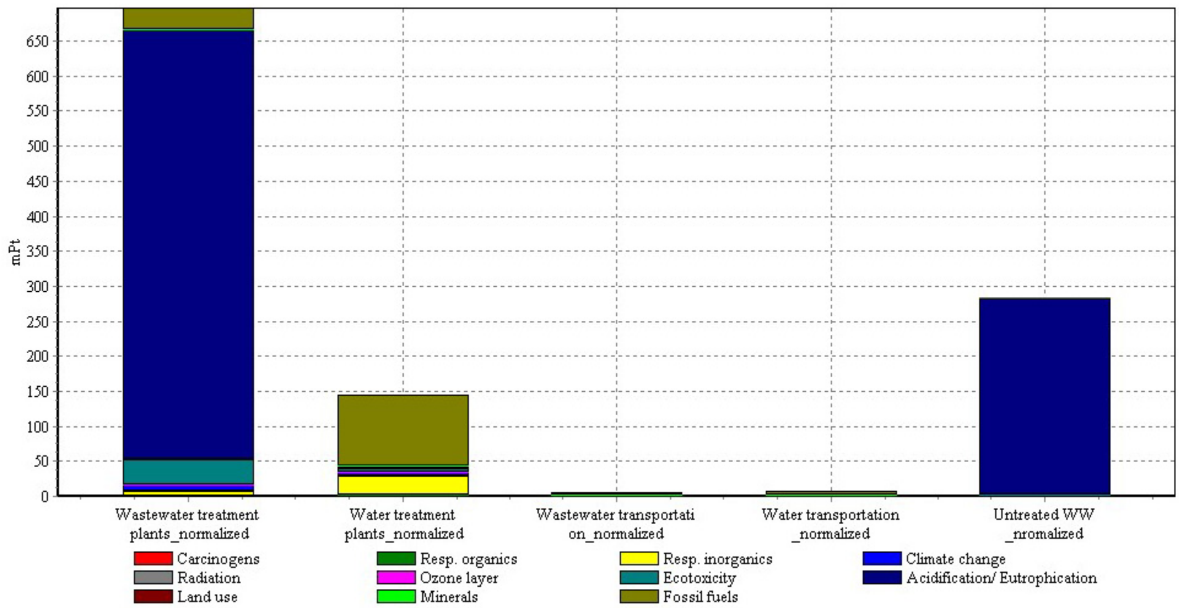

Figure 4.3: Normalized impact of the main compartments of the system.

4.2 The critical processes in the system

The identification of the critical processes which have higher environmental impacts can give more insight into the hot spots in the system ,and hence enables the identification of the ways that can be used for improving the environmental performance of the system. The assessment of the system revealed that there's four main processes that have the highest environmental impacts, these processes are:

1. Discharge of nutrients-rich wastewater into Lake Mariout and Mediterranean Sea: That causes eutrophication problems in Lake Mariout and could cause eutrophication

problems in the sea but not as serious as the impact on the lake. The eutrophication and acidification impact category represents about 70.7 % of the total impact.

2. The energy consumption: the use of electricity generated from fossil fuel has a very negative impact on the environment, firstly it is considered a depletion of non-renewable resource, and secondly it increases the climate change. The fossil fuel category represents about 19 % of the total impact of the system.

3. The use of chemicals: the chemicals use cause respiratory effects caused by the use of inorganic substances. The chemicals use is mainly in the water treatment and also with fewer amounts in the wastewater treatment. The respiratory inorganic category represents about 4.8 % of the total impact of the system

4. Land application of sludge: the presence of the heavy metals in the sludge resulted in negative impacts on the soil which leads to eco-toxicity. The eco-toxicity represents about 3.9 % of the total impact.

The four aforementioned processes represent about 98 % of the total environmental impact of the system. However, the first two processes (discharge of nutrients-reach effluent into the water bodies and the energy use) have the highest impacts which represent about 90% of the total impact of the system, so more attention will be paid for them in improving the system. Figure 4.4 shows the critical process in the system and the contribution of the different compartments of the system in each category.

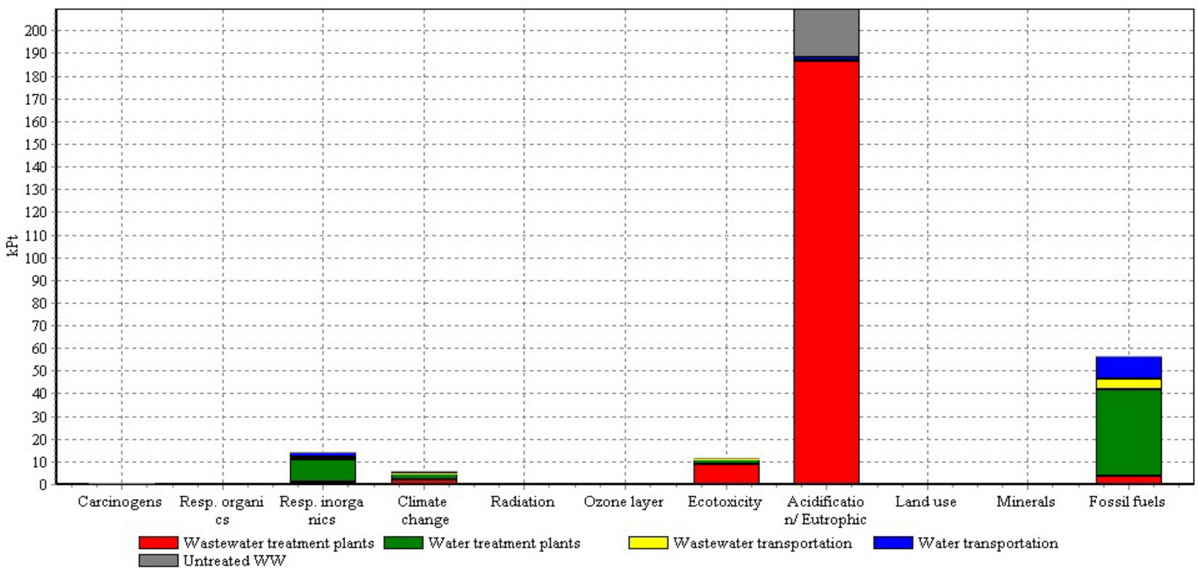

Figure 4.4: The critical processes in the system**.**

4.2.1 Sensitivity analysis of the critical parameters

The parameters that were chosen to conduct sensitivity analysis are based on the critical processes mentioned in the previous section; those parameters are:

- Nutrients concentration (phosphorous and nitrogen) at the effluent of the wastewater treatment plants,
- The energy use, and
- The characterisation factors of total nitrogen, total phosphorous, and COD

The results of the sensitivity analysis are shown in Table 4.6. The relative sensitivity was calculated according to Equation 3.4 based on 100% change in the values of the selected parameters.

Table 4.6: Relative sensitivity of the selected parameters

Parameter	Change in the nominal value of the parameter (%)	Relative sensitivity (%)
Nitrogen concentration	100	5.0
Phosphorous concentration	100	25.5
Energy use	100	18.1
Characterization factor of N_{total}	100	5.0
Characterization factor of P_{total}	100	25.5
Characterization factor of COD	100	4.0

The relative sensitivity in Table 4.5 showed that 100% change in the concentration of the phosphorous, and 100% change in the amount of energy used in the system could decrease the total impact of the system by about 25.5% and 18.1% respectively, while the same change in the concentration of nitrogen could only decrease the total impacts of the system by about 5%. Also the same change in the characterisation factors of the total nitrogen, the total phosphorous, and the COD caused relative sensitivity 5%, 25.5%, and 4% respectively.

The most sensitive parameters were the phosphorus concentration, the characterisation factor of phosphorus, and the energy use. So, these parameters and the parameters (or processes) with high contribution to the total impact will be taken into consideration in proposing improvement scenarios.

4.3 Scenario analysis of the improvement potentials

In this section the possible scenarios for improving the system will be proposed, and then an assessment of theses scenarios will be carried out based on the LCA methodology.

4.3.1 The proposed scenarios

The improvement scenarios can be categorized into the following categories:

- Technical intervention: In this category the possible technical means that can improve the critical processes of the system will be proposed.

- Better management of the system: Improving the management of the system could improve the performance of the system, so the management practices that could be used will be proposed.
- Paradigm shift: As the current system is not efficient, so new paradigm could be the solution for improving the system especially for the future.

According to the two aforementioned categories; improvement scenarios were proposed. The scenarios that were analyzed in this research are listed here after:

1. **Technical Intervention:**

   a. Scenario No.1: Upgrade the primary treatment plants to be secondary treatment with nitrogen and phosphorous removal units by the use of activated sludge technology. The sludge treatment will be kept as it is in the current situation. The treated effluent will be used in irrigation, so the effluent will be send to sand filter and chlorination unit.

   b. Scenario No.2: The use of the green energy in pumping of water and wastewater by the use of solar energy pumps.

2. **Better Management:**

   a. Scenario No.3: This scenario will depend on decreasing the losses in the drinking water distribution network to be 10 % instead of 35 % currently. In addition to demand management for decreasing the demand of water with about 15 %.

   b. Scenario No.4: Extending the sewerage network to collect the uncollected wastewater, then this water in addition to the water that discharged to the sea without treatment will be send to be treated (the capacity of the wastewater treatment plants can handle this amount). This amount of water is about 81,000 cubic meters per day.

3. **Paradigm shift:**

   a. Scenario No.5: A decentralized wastewater treatment system proposed by Tillman et al. (1998) will be analysed. The system based on the separation of different kinds of waste to be treated separately. The system separates the urine, the faeces, and the grey water. The urine will be used in agriculture directly. The faeces will be dried using drying beds and then transported to be used for land application. The grey water will be pre-treated to separate the sludge which will be dried and reused for land application and then the effluent of the pre-treatment will send to sand filter beds to be treated and reused in irrigation. Schematic of the system adapted to Alexandria situation and the data used for analysing the system are shown in Annex C.

It is obvious that the above system will be used only for the domestic wastewater. So, it will be assumed that the industrial wastewater in addition to the storm water will be handled in the same way that is used in the current situation.

b. Scenario No.6: In this scenario the same system used in the previous scenario will be used for the treatment of the domestic wastewater. In addition the industrial wastewater and the storm water will be treated in an activated sludge plant with nutrients removal unit in the same way as the first scenario.

4.3.2 Analysis of the proposed scenarios

Applying the same methodology of the LCA and by the use of SimaPro Software the proposed scenarios were analyzed to assess the environmental impacts of each scenario. The results of the analysis are presented here after.

4.3.2.1 Scenario No.1 (activated sludge)

Data from Teng (2006) was used for analysing this scenario where similar system was assessed. However, the characteristics of the effluent were calculated assuming that the removal efficiency is 95 %. As mentioned above the treated effluent will be used in irrigation, so there will not be water emissions resulted from the treatment, in addition the nutrients in the effluent will be considered as fertilizers. The dose of chlorine used for disinfection is 25mg/l (Andreadakis et al., 2003). The normalized data of this scenario are presented in Annex C.

The overall reduction of the environmental impact by this scenario compared with the current situation is about 50.7% that is mainly due to a reduction of the impact of the wastewater treatment plants by about 74.5%. The changes in the environmental impacts due to the use of this scenario if it is compared with the current situation are shown in Table 4.7.

Important to note that the only impact that is decreased in the wastewater treatment plants if it is compared with the current situation is in the category of eutrophication (about 96.2% reduction), while the impact of the others categories are increased especially the land use (1259.8% increase in the impact) and the Minerals (74233.22% increase in the impact).

Table 4.7: The change in the environmental impacts of the system in the case of using Scenario No.1 if it is compared with the current situation.

Impact category	Unit	Total	WWTPs	Water treatment plants	Wastewater transp.	Water transp.	Untreated WW
Carcinogens	%	34.19	518.93	0.0	0.0	0.0	0.0
Resp. organics	%	35.24	501.12	0.0	0.0	0.0	0.0
Resp. inorganics	%	33.10	550.18	0.0	0.0	0.0	0.0
Climate change	%	44.13	106.90	0.0	0.0	0.0	0.0
Radiation	%	0.00	0.00	0.0	0.0	0.0	0.0

Impact category	Unit	Total	WWTPs	Water treatment plants	Wastewater transp.	Water transp.	Untreated WW
Ozone layer	%	32.41	465.69	0.0	0.0	0.0	0.0
Ecotoxicity	%	37.93	48.48	0.0	0.0	0.0	0.0
Acidification/ Eutrophication	%	-85.71	-96.24	0.0	0.0	0.0	0.0
Land use	%	1259.79	1259.79	0.0	0.0	0.0	0.0
Minerals	%	7423.22	10241.88	0.0	0.0	0.0	0.0
Fossil fuels	%	32.57	487.30	0.0	0.0	0.0	0.0
Total	%	-50.00	-73.71	0.0	0.0	0.0	0.0

4.3.2.2 Scenario No.2 (green energy)

The use of green energy decreased the environmental impacts of water transportation, wastewater transportation, and the water treatment by about 100%, 100%, and 83.8% respectively; because the impact of the aforementioned compartments of the system depends greatly on the impact of the use of fossil fuel on the energy generation. However, the reduction in the environmental impact of the wastewater treatment plants is very small (about 1%). the overall reduction on the environmental impact of the system is about 23%. Table 4.8 shows the effect of using this scenario on the environmental impacts of the system.

Table 4.8: The change in the environmental impacts of the system in the case of using Scenario No.2 if it is compared with the current situation.

Impact category	Unit	Total	WWTPs	Water treatment plants	Wastewater transp.	Water transp.	Untreated WW
Carcinogens	%	-81.8	-39.1	-79.4	-100.0	-100.0	0.0
Resp. organics	%	-85.0	-38.2	-84.1	-100.0	-100.0	0.0
Resp. inorganics	%	-78.1	-41.0	-73.9	-100.0	-100.0	0.0
Climate change	%	-52.7	-3.9	-83.6	-100.0	-100.0	0.0
Radiation	%	0.0	0.0	0.0	0.0	0.0	0.0
Ozone layer	%	-87.6	-39.5	-87.7	-100.0	-100.0	0.0
Ecotoxicity	%	-21.9	-1.0	-87.2	-100.0	-100.0	0.0
Acidification/ Eutrophication	%	-1.0	0.0	-74.3	-100.0	-100.0	0.0
Land use	%	0.0	0.0	0.0	0.0	0.0	0.0
Minerals	%	0.0	0.0	0.2	0.0	0.0	0.0
Fossil fuels	%	-87.1	-41.0	-86.7	-100.0	-100.0	0.0
Total	%	-22.8	-1.0	-83.8	-100.0	-100.0	0.0

4.3.2.3 Scenario No.3 (losses and demand reduction)

Decreasing the water demands by 15% and the distribution network losses by 25% not only will lead to decrease the total amount of drinking water that have to be produced by the system by about 40 %, but also they will decrease the amount of the wastewater that have to be treated with about 14 %. Moreover, the amount of drinking water that has to be transported will decrease by 40%, and the amount of wastewater that has to be transported will be decreased by about 14%. . However, the concentration of the nutrients in the wastewater is increased due to the reduction in the amount of the wastewater.

The use of this scenario caused reduction in the impact of all the compartments of the system. The impact of the WWTPs, the water treatment plants, the wastewater transportation, the water transportation and the untreated wastewater are decreased by about 0.24%, 40.04%, 13.6%, 40%, and 0%. The total reduction in the impact of the system is about 9.4%. Table 4.9 shows the change in the impact of all the compartments of the system if it is compared with the current situation.

Table 4.9: The change in the environmental impacts of the system in the case of using Scenario No.3 if it is compared with the current situation.

Impact category	Unit	Total	WWTPs	Water treatment plants	Wastewater transp.	Water transp.	Untreated WW
Carcinogens	%	-35.78	-8.74	-40.00	-13.55	-39.80	0.00
Resp. organics	%	-35.63	-8.71	-40.06	-13.61	-39.95	0.00
Resp. inorganics	%	-36.13	-9.31	-40.04	-13.45	-39.82	0.00
Climate change	%	-21.89	-0.86	-39.91	-13.42	-40.03	0.00
Radiation	%	0.00	0.00	0.00	0.00	0.00	0.00
Ozone layer	%	-35.59	-9.31	-39.98	-13.85	-39.92	0.00
Ecotoxicity	%	-8.62	-0.34	-39.80	-13.69	-39.96	0.00
Acidification/ Eutrophication	%	-0.48	0.00	-39.82	-13.74	-40.00	0.00
Land use	%	0.00	0.00	0.00	0.00	0.00	0.00
Minerals	%	-11.15	0.00	-39.98	0.00	0.00	0.00
Fossil fuels	%	-35.58	-9.26	-40.11	-13.52	-39.98	0.00
Total	%	-9.40	-0.24	-40.04	-13.60	-40.00	0.00

4.3.2.4 Scenario No.4 (treatment of untreated wastewater)

The total impact of the system when using this scenario will be decreased by about 0.3%. The highest and the only reduction was in the untreated wastewater compartment which decreased by 100%. The impact of the wastewater treatment plants increased by about 9.9%, also the

impact of the wastewater transportation is increased by about 6.9%. The impacts of the other compartments of the system didn't change. Table 4.10 shows the change in the impacts of the main compartments of the system.

It is important to note that this scenario showed increase in the eutrophication and acidification caused by the WWTPs by about 9.6% and by the wastewater transportation by about 6.9%. But the eutrophication and acidification caused by the untreated wastewater was decreased by 100%. In total the eutrophication and acidification caused by the whole system was decreased by about 1.9%.

Table 4.10: The change in the environmental impacts of the system in the case of using Scenario No.4 if it is compared with the current situation.

Impact category	Unit	Total	WWTPs	Water treatment plants	Wastewater transp.	Water transp.	Untreated WW
Carcinogens	%	1.1	10.0	0.0	6.9	0.0	0.0
Resp. organics	%	1.2	10.1	0.0	7.0	0.0	0.0
Resp. inorganics	%	0.7	9.9	0.0	7.1	0.0	0.0
Climate change	%	3.0	10.3	0.0	7.0	0.0	-100.0
Radiation	%	0.0	0.0	0.0	0.0	0.0	0.0
Ozone layer	%	1.4	9.8	0.0	6.9	0.0	0.0
Ecotoxicity	%	8.6	10.9	0.0	6.8	0.0	0.0
Acidification/ Eutrophication	%	-1.9	9.6	0.0	6.9	0.0	-100.0
Land use	%	3.7	3.7	0.0	0.0	0.0	0.0
Minerals	%	2.5	3.8	0.0	0.0	0.0	0.0
Fossil fuels	%	1.2	9.8	0.0	7.0	0.0	0.0
Total	%	-0.3	9.9	0.0	6.9	0.0	-100.0

4.3.2.5 Scenario No.5 (decentralized WWTPs for household wastewater)

The adaptation of this scenario caused reduction in the impacts of all the compartments of the system especially the WWTPs (70.3% reduction) and the wastewater transportation (73.7% reduction). The total reduction in the environmental impact of the system was about 54.4%. It is Important to mention that the eutrophication in this scenario resulted mainly from the industrial waste which assumed to be handled using the current system. Table 4.11 shows the change in the impacts of the main compartments of the system.

Table 4.11: The change in the environmental impacts of the system in the case of using Scenario No.5 if it is compared with the current situation.

Impact category	Unit	Total	WWTPs	Water treatment plants	Wastewater transp.	Water transp.	Untreated WW
Carcinogens	%	-9.3	82.0	-10.0	-73.7	-9.8	0.0
Resp. organics	%	-3.7	158.1	-9.9	-73.7	-10.0	0.0
Resp. inorganics	%	-18.3	-66.7	-10.0	-73.6	-10.0	0.0
Climate change	%	-48.2	-90.8	-10.3	-73.7	-10.0	-38.0
Radiation	%	0.0	0.0	0.0	0.0	0.0	0.0
Ozone layer	%	-9.0	85.3	-10.1	-73.8	-9.9	0.0
Ecotoxicity	%	-14.2	-13.8	-9.7	-73.7	-9.9	0.0
Acidification/ Eutrophication	%	-66.1	-69.8	-9.6	-73.7	-10.2	-37.9
Land use	%	-71.5	-71.5	0.0	0.0	0.0	0.0
Minerals	%	-54.5	-71.5	-10.0	0.0	0.0	0.0
Fossil fuels	%	-30.3	-227.0	-10.0	-73.6	-10.1	0.0
Total	%	-54.4	-70.3	-9.9	-73.7	-10.4	-38.1

4.3.2.6 Scenario No.6 (decentralized WWTPs for household wastewater and activated sludge for other kinds of wastewater)

A significant reduction in the impact of all the system compartments was noticed due to the use of this scenario. The highest reduction was in the impact of the WWTPs by about 82.1%; most of this reduction was in the categories of climate change, eco-toxicity, acidification and eutrophication, and fossil fuel. However, there was an increase in the impact of WWTPs with respect to carcinogens, respiratory inorganics, respiratory organics and minerals.

The impact of wastewater transportation showed a very high reduction with about 73.7 %. The impact of the other compartments of the system also decreased but with less values than in the case of WWTPs and wastewater transportation. The impacts of the water treatment plants, the water transportation, and the untreated wastewater are decreased by 9.87%, 10.4 %, and 38.1% respectively.

The total reduction in the total impact of the system was about 62.4%. The impact of this scenario if it is compared with the current situation is shown in Table 4.12

Table 4.12: The change in the environmental impacts of the system in the case of using Scenario No.6 if it is compared with the current situation.

Impact category	Unit	Total	WWTPs	Water treatment plants	Wastewater transp.	Water transp.	Untreated WW
Carcinogens	%	3.83	283.50	-10.00	-73.66	-9.80	0.00
Resp. organics	%	9.84	355.06	-9.94	-73.70	-9.99	0.00
Resp. inorganics	%	-5.63	149.71	-10.01	-73.63	-9.95	0.00
Climate change	%	-30.07	-49.57	-10.30	-73.66	-9.97	-38.05
Radiation	%	0.00	0.00	0.00	0.00	0.00	0.00
Ozone layer	%	3.45	265.69	-10.07	-73.77	-9.88	0.00
Ecotoxicity	%	-5.17	-2.47	-9.69	-73.69	-9.94	0.00
Acidification/ Eutrophication	%	-82.76	-88.40	-9.65	-73.74	-10.20	-37.85
Land use	%	422.22	422.22	0.00	0.00	0.00	0.00
Minerals	%	2838.08	3921.37	-10.02	0.00	0.00	0.00
Fossil fuels	%	-17.52	-36.51	-10.03	-73.56	-10.07	0.00
Total	%	-62.42	-82.08	-9.87	-73.66	-10.37	-38.14

5 Interpretation of the Environmental Impacts

In this chapter the environmental impacts of Alexandria's urban water system (and its compartments) and the proposed scenarios will be discussed. Then, the basis for choosing the best scenario will be discussed. Finally general discussions about the data reliability and the integrated approach will be presented.

5.1 Environmental impacts of Alexandria's urban water system

In this section the results of the environmental impacts of the system including water treatment and transportation, wastewater treatment and transportation, and the untreated wastewater will be discussed.

5.1.1 Environmental impacts of water treatment

Most of the impacts of the water treatment plants were due to the energy use, as can be seen in Figure 5.1, it shows that the highest impacts of all the plants are in the category of fossil fuel which used in the power generation in Alexandria. So, the pumping process (whether raw water pumping or clean water pumping) in the water treatment plants were the most critical process with higher impact than the other processes and its impact represented about 91% of the total impact of all the water treatment plants. This result is consistent with the results of Mohapatra et al. (2002) and Friedrich et al. (2002) who concluded that the energy use is the dominant cause of the environmental impact in the water treatment plants, but the most problematic processes was different due to the different water treatment systems studied by them.

The impact of the chemicals use was significant but it was very low if it is compared with the impact of the energy, the impact of Aluminium sulphate represented about 5.2% of the total impact and the impact of chlorine represented about 2.6% of the total impact.

The impact of clarification, filtration, and chlorination was mainly due to the use of chemicals which had low impact, so their impact was very low if it is compared with the impact of pumping. Hence, it can be concluded that the pumping process has to be improved.

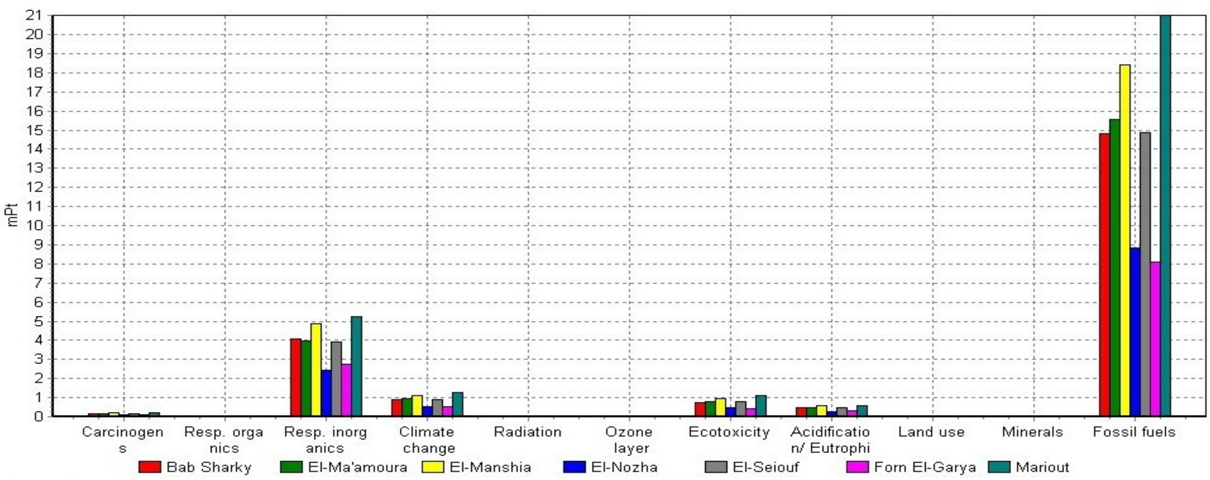

Figure 5.1: Environmental impacts of the water treatment plants (eco-points/m^3).

It was noticed that in general the impact of all the plants showed the same trend where the impact per cubic meter were almost the same in all the plants as shown in Figure 5.2; that is mainly due to the fact that the treatment system in all the plants is the same. The only exceptions were El-Nozha and Forn El-Garya plants which their impact was less than the other plants, the reason for that is the fact that the two plants don't have raw water pumps which reflected on the total energy use of the two plants that led to decrease their impact.

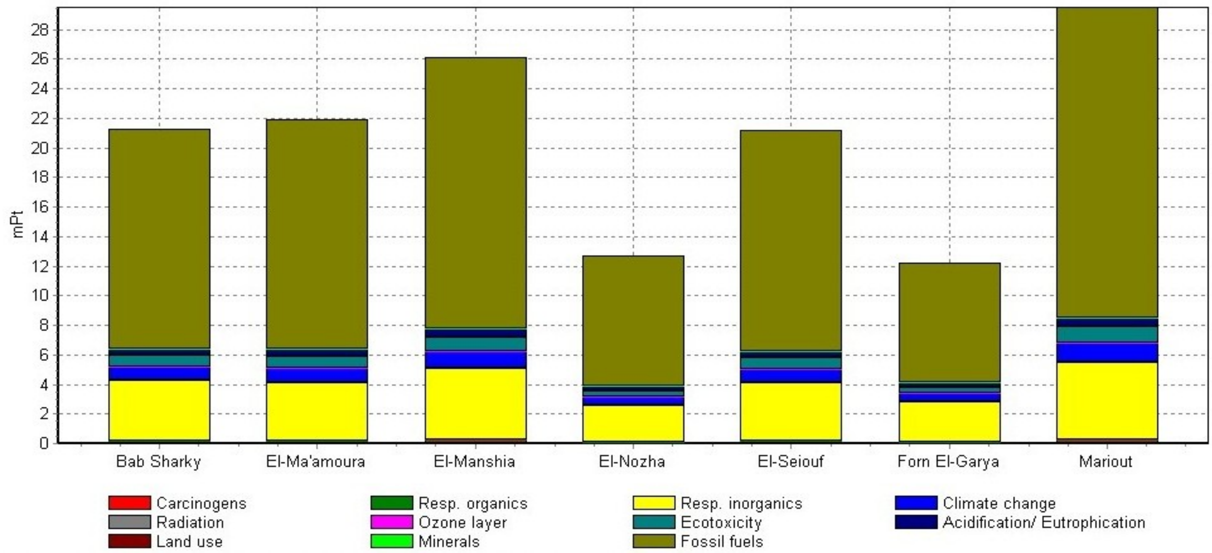

Figure 5.2: Environmental impact of the water treatment plant (eco-points/m^3).

5.1.2 Environmental impacts of wastewater treatment

The impacts of the wastewater treatment plants varied due to the variation in the wastewater characteristics treated by each plant and due to the treatment efficiency (affects final effluent characteristics) in each plant. The east WWTP and the west WWTP (primary treatment) showed higher impact than the other two plants (secondary treatment) as shown in Figure 5.3, because their treatment efficiency is less than the other WWTPs.

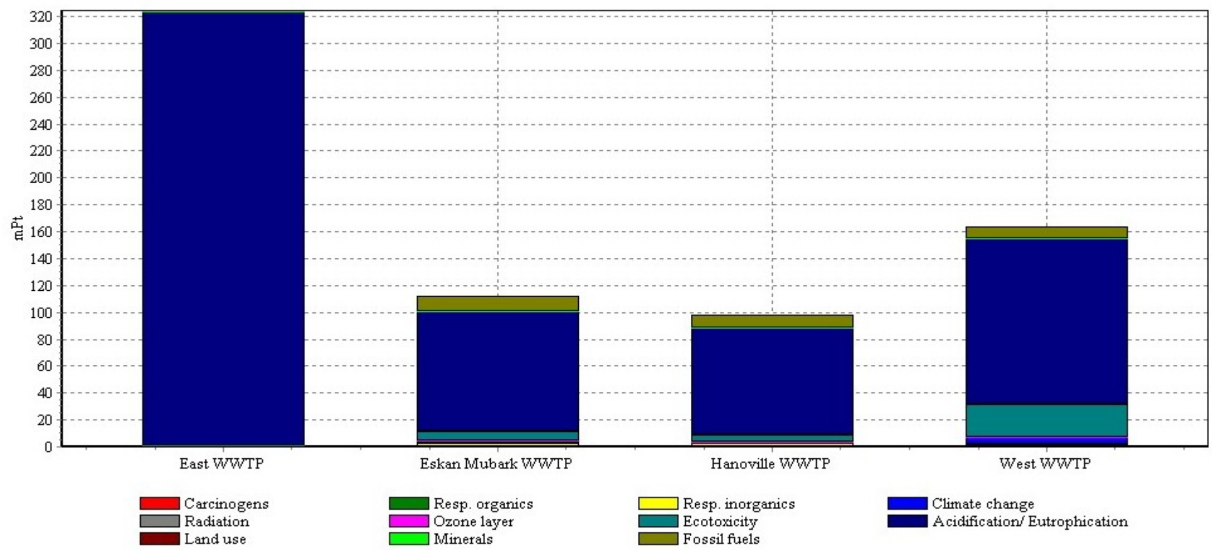

Figure 5.3: Environmental impact of the wastewater treatment plants (eco-points/m^3).

Furthermore, most of the impact of the wastewater treatment plants was due to three main factors: (1) The nutrients in the final effluent that discharged into Lake Mariout or the Mediterranean Sea, which leads to eutrophication problems, (2) The land application of sludge because the sludge contains heavy metals which resulted in negative impacts on the soil, that leads to eco-toxicity, and (3) Energy consumption due to the use of fossil fuel in power generation that lead to depletion of fossil fuel and increase climate change. However, the main source of the impact was the nutrients, and hence the impact in the eutrophication category was higher than the other categories as shown in Figure 5.4, the same result was reported by Almudena et al. (2004) who specified the eutrophication and terrestrial toxicity as the most dominant causes of the environmental impacts in WWTPs.

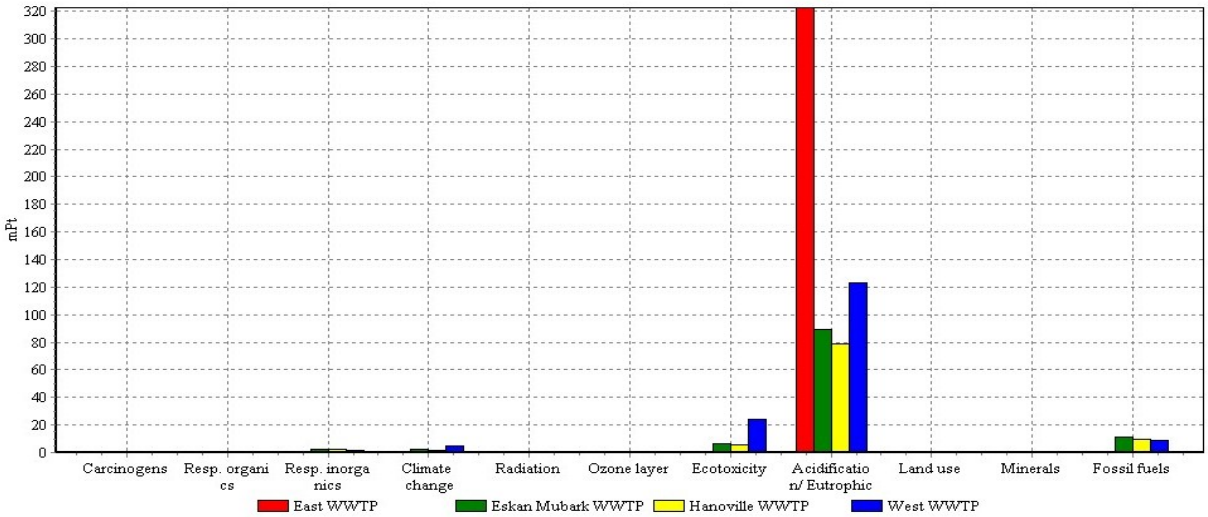

Figure 5.4: Environmental impacts of the wastewater treatment plants with respect to the different impact categories (eco-points/m^3).

It has to be mentioned that although the treatment system in the east WWTP and the west WWTP is the same, but the impact of the east WWTP (0.32 eco-points/m^3) was higher than the impact of the west WWTP (0.16 eco-points/m^3), this is due to the higher concentration of the nutrients in the effluent of the east WWTP that increase the eutrophication which was the main source of the impacts of the wastewater treatment plants as mentioned above.

The impact of the heavy metals in the effluent of the WWTPs wasn't taken into consideration. The main reason for that is the very low contribution of the impact of the heavy metals to the total impact of the WWTPs. Based on literature data (because no measured data bout the concentrations of the heavy metals in the effluent or influent of the wastewater treatment plants were found) the impact of the heavy metals was about 1.8% of the total impact of the WWTPs.

On the other hand, the results of the assessment of the environmental impacts of the WWTPs could be affected by the characterization factors for nutrients and COD that were added because the assessment method lacked the impacts of these parameters with respect to water emissions (as mentioned in section 3.4.3). The characterization factors based on rough estimation which could affect their accuracy, and hence the accuracy of the overall results.

5.1.3 Environmental impacts of the untreated wastewater

The untreated wastewater (industrial and domestic) caused eutrophication problems due to the presence of the nutrients in the untreated wastewater which discharged into the water bodies. The impact of the untreated wastewater was only eutrophication impact and impact on climate change, the impact on climate change resulted from the possible degradation of COD. The degradation of COD assumed to produce CO_2 emissions as half as the amount of CO_2 that is resulted in the degradation of COD in the wastewater treatment plants.

It is noticed that the impact per cubic meter of the east WWTP (0.32 eco-points/m^3) was higher than the impact per cubic meter of the untreated wastewater (0.28 eco-points/m^3), this result has to be used carefully because the characteristics of the untreated wastewater was assumed to be as the average of all the influent of the four WWTPs and that is only a simplification which is not very true.

As the case of the wastewater treatment plants, the impact of the emission of the heavy metals into the water bodies was not taken into consideration due to the same reason mentioned in the previous section. The impacts of untreated wastewater with respect to the different impact categories are shown in Figure 5.5.

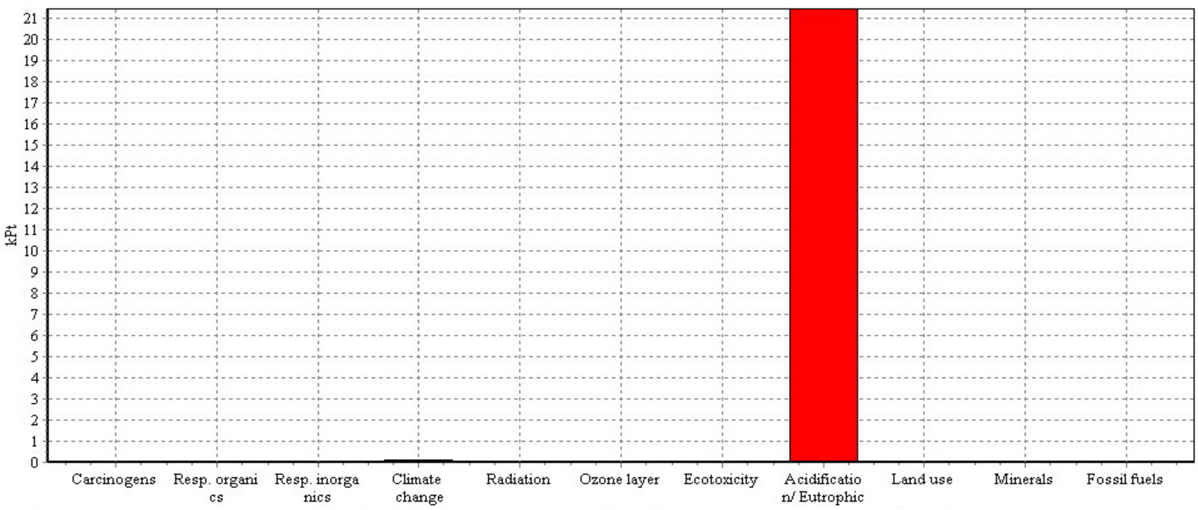

Figure 5.5: Total impacts of the untreated wastewater with respect to the different impact categories (eco-points).

5.1.4 Environmental impacts of transportation of water and wastewater

The energy consumption was the main driving force of the environmental impacts of the transportation of water and wastewater. So, most of the impact was in the category of fossil fuel (which is used in electricity generation) and respiratory inorganic which is indirectly affected by the use of fossil fuel.

The transportation of water showed higher impact than the impact of the wastewater transportation due to the higher energy consumption in the pumping of drinking water than of

pumping wastewater. Figure 5.6 shows the environmental impact of the transportation of water and wastewater with respect to the different impact categories.

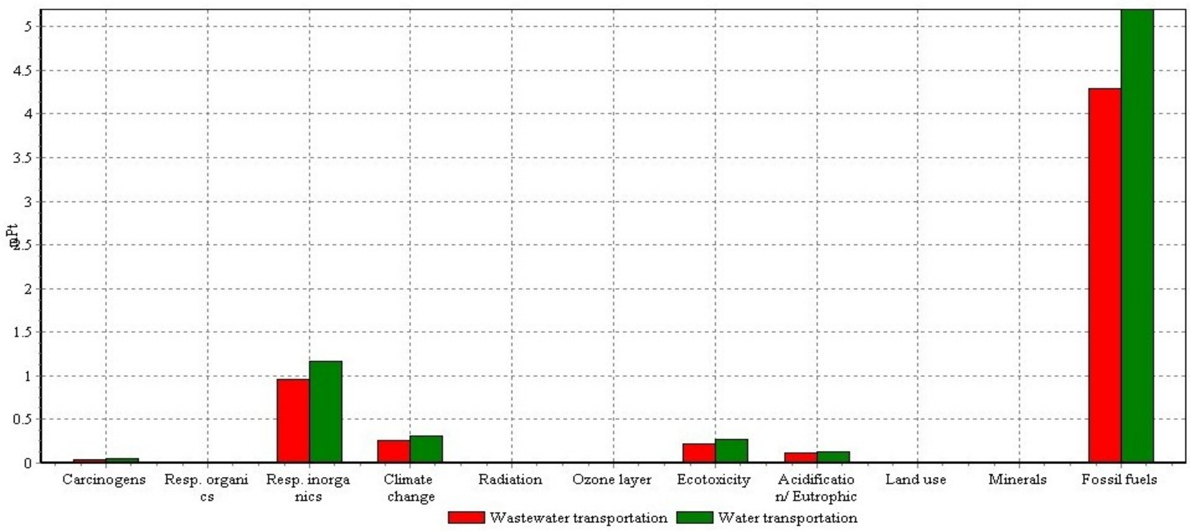

Figure 5.6: Environmental impact of the transportation of water and wastewater (eco-points/m^3).

5.1.5 Contribution of each compartment to the total impact of the system

Most of the impact of Alexandria's urban water system (about 67.8% of the total impact) was due to the WWTPs, this result seems to be common in most of the studies carried out in the urban water systems (such as Rihon et al ,2002) in spite of the differences between the systems studied by the different researchers. This result can lead to the conclusion that the current wastewater treatment schemes are not sustainable and it has to be improved.

The second important compartment was the water treatment plants (18.02% of the total impact), that was mainly due to the use of electricity generated by fossil fuel (the same result was reported by Mohapatra et al. (2002), and Friedrich et al. (2002)). The same impact of fossil fuel- generated electricity noticed also in the water and wastewater transportation, but the contribution of the water and wastewater in the total impact of the system was very low if it is compared with the water and wastewater treatment (4.53%, and 2.32% respectively).

The untreated wastewater also showed significant contribution from the total impact of the system (7.21%). This impact was mainly due to the discharge of the untreated wastewater into the water bodies which causes eutrophication problems.

Due to the high contribution of the WWTPs in the total impact, more attention has to be paid for the improvement of the WWTPs. However, the possible ways for improving the other compartments of the system have to be identified and adapted to improve the system in an integrated way.

5.2 Scenario analysis of the improvement potentials

In this section the results of the scenario analysis for improving the system and then the basis for choosing the best scenario will be discussed. In addition, the best scenario will be chosen.

5.2.1 Analysis of the proposed scenarios

Six scenarios were proposed and their results are presented in the previous chapter, the discussion of the results of the proposed scenarios will be introduced here after.

5.2.1.1 Scenario No.1 (activated sludge)

This scenario was mainly for improving the WWTPs, so the only compartment that had reduction in its impact was the WWTPs. The reduction in the impact of the WWTPs was due to the improved removal efficiency of the nutrients which is the major problem in the current situation; the improved treatment resulted in decrease in eutrophication problem, and that reflected on the total impact of the WWTPs and hence the total impact of the system is decreased with about 50.7%.

However, the new wastewater treatment technology has higher energy consumption than the current facilities, so the total consumption of energy by the system was increased which reflected on the depletion of fossil fuel as shown in Figure 5.7. The tertiary treatment and the reuse of the treated effluent in irrigation minimized the possibility of eutrophication problems which is the main impact category in the current situation. The only source of eutrophication in this scenario was the discharge of the untreated wastewater into Lake Mariout.

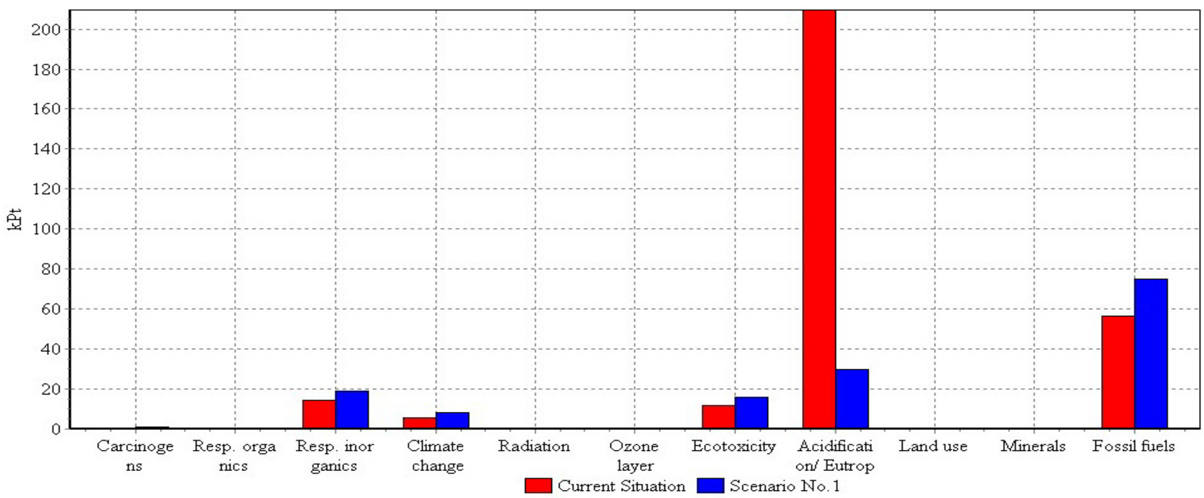

Figure 5.7: comparison between the impacts of scenario No.1 and the current situation on the different impact categories.

5.2.1.2 Scenario No.2 (green energy)

The use of green energy caused reduction in the depletion of fossil fuel (which is currently used in electricity generation) by about 87.1% which reflected on the total impact of the system; the overall reduction on the environmental impact of the system was about 23%. The impacts of this scenario with respect to the different impact categories compared with the current situation are shown in Figure 5.8.

This scenario caused reduction in the impact of transportation of water and wastewater and reduction in the impact of the water treatment plants that is due to the fact that the energy consumption represented most of the impact of the aforementioned compartments. While the impact of WWTPs wasn't affected much because the energy use in the WWTPs is very low if it is compared with the transportation and the water treatment. It is also noticed that the impact on the category of respiratory inorganic was decreased significantly, that is also due to the reduction in the use of fossil fuel.

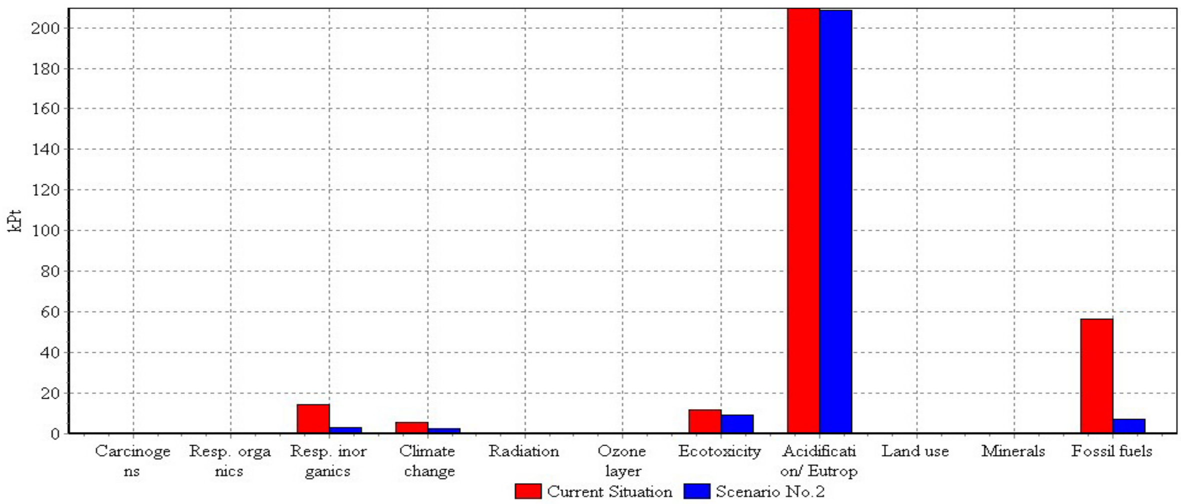

Figure 5.8: comparison between the impacts of scenario No.2 and the current situation on the different impact categories.

5.2.1.3 Scenario No.3 (losses and demand reduction)

The adaptation of this scenario caused reduction in the amount of water that has to be treated, the amount of water that has to be transported, the amount of wastewater that has to be transported, and the amount of wastewater that has to be treated. This reduction caused reduction in the total impact of the system by 9.4% as shown in Figure 5.9.

In spite of the reduction of the amount of wastewater that has to be treated, but the total reduction in the impact of the wastewater treatment plants is very small (0.24%), that is due to the fact that the reduction in the amount of the wastewater usually accompanied with increase in the nutrients concentration. So, the impact on eutrophication wasn't improved in this scenario which reflected on the total impact of the wastewater treatment plants because eutrophication represents more than 90% of the total impact of the WWTPs.

The highest reduction in this scenario was in the category of fossil fuel (used in electricity generation) due to the reduction in the amount of water that has to be treated as well as the reduction of the amount of water and wastewater that have to be transported. So, the reduction in the three aforementioned compartments was higher than the other compartments. However, due to the high contribution of the WWTPs from the total impact, the reduction in the impacts of the aforementioned categories didn't reduce the total impact of the system much.

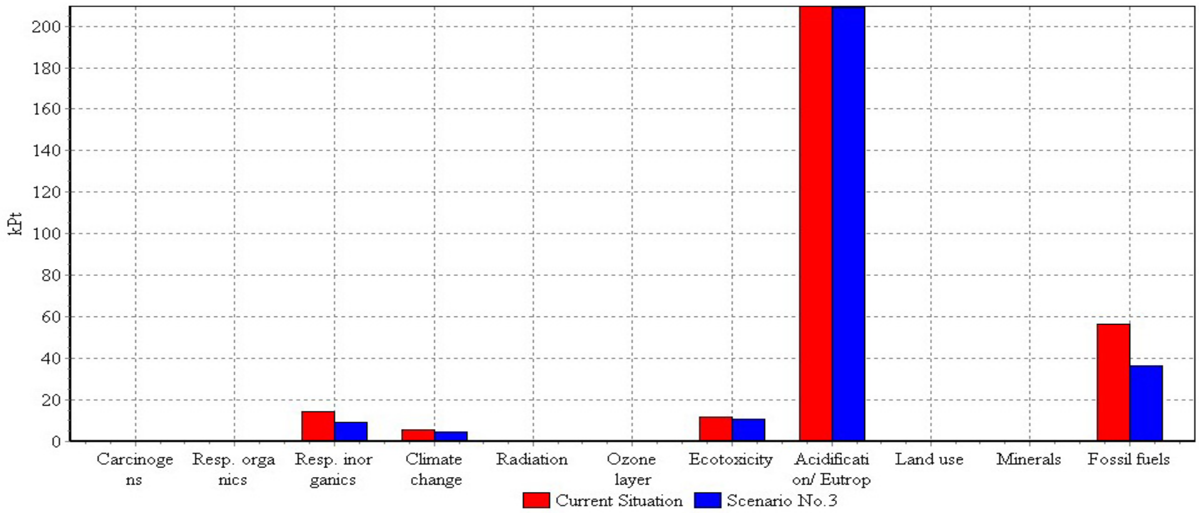

Figure 5.9: comparison between the impacts of scenario No.3 and the current situation on the different impact categories.

5.2.1.4 Scenario No.4 (treatment of untreated wastewater)

Although this scenario assumed that all the wastewater will be treated using the current treatment facilities which means that no raw wastewater will be discharged directly to the water bodies, but the reduction in the environmental impacts of the system is very low (about 0.3% reduction). That is due to the low treatment efficiency in the current wastewater treatment plants especially the removal of nutrients.

Figure 5.10 shows the increase or the reduction in the different impact categories due to the adaptation of the current scenario. Most of the impacts increased or unchanged except the category of eutrophication. The increase in the impact in some impact categories (such as fossil fuel, eco-toxicity, and climate change) was due to the increase in the energy use and the increase in the sludge resulted from the treatment process because of the additional wastewater that has to be treated by the WWTPs.

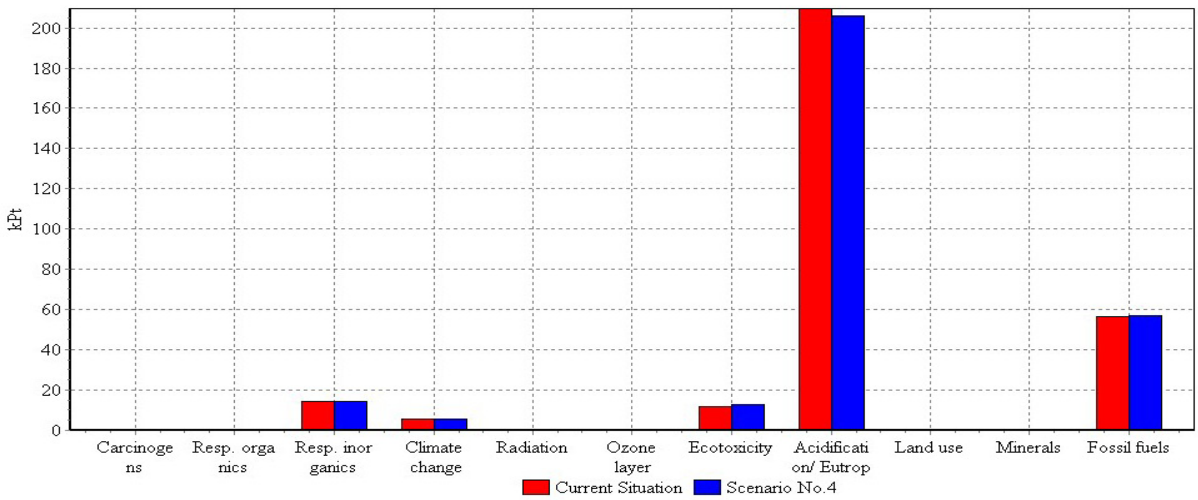

Figure 5.10: comparison between the impacts of scenario No.4 and the current situation on the different impact categories.

5.2.1.5 Scenario No.5 (decentralized WWTPs for household wastewater)

The decentralized wastewater treatment system will decrease the energy consumption in the wastewater transportation, because there will be no need for transporting the wastewater from the households that cause reduction in the depletion of fossil fuel as shown in Figure 5.11. In addition, the use of the separation system will decrease the water consumption (about 10% reduction in the water consumption) which is reflected on the total impact of the system. Moreover, because of the reuse of urine and faeces in agriculture the emissions of the nutrients from the household wastewater are decreased significantly.

It was assumed that the storm water and the industrial wastewater will be kept to be handled in the current system and the improvement of the system will include the wastewater from the household only. So, although the proposed scheme for treatment will improve the removal efficiency of the nutrients but the eutrophication impact is still very high due to the high nutrients concentration in the treated industrial wastewater.

This scenario demonstrates that the decentralized WWTPs have lower impacts than the centralized ones. The same result was reported by Lassaux et al. (2001) and Tillman et al. (1998).

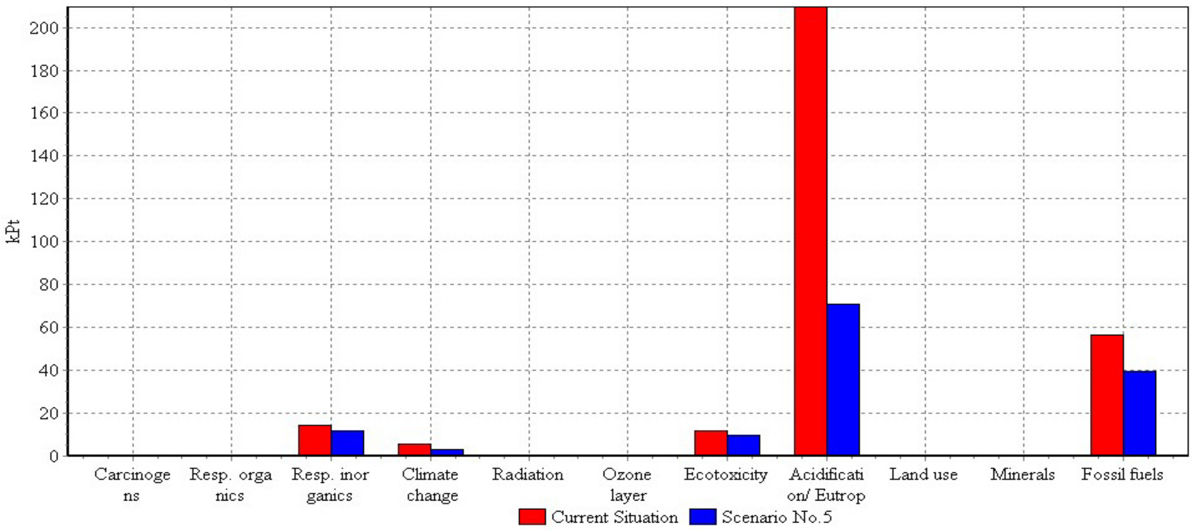

Figure 5.11: comparison between the impacts of scenario No.5 and the current situation on the different impact categories.

5.2.1.6 Scenario No.6 (decentralized WWTPs for household wastewater and activated sludge for other kinds of wastewater)

This scenario is similar to the previous scenario; the only difference is the use of activated sludge and tertiary treatment for treating the industrial wastewater and the storm water while in the previous scenario they were treated in the current system. So, more reduction in the total impact of the system was reported due to the increased removal efficiency of the nutrients resulted from the industrial wastewater and the storm water.

The highest reduction was in the category of eutrophication and acidification. Also the depletion of fossil fuel was decreased because of the reduction in the energy used of wastewater transportation, but the total reduction in the energy consumption was less than the previous scenario due to the use of activated sludge technology which uses more energy than the primary treatment. Figure 5.12 shows the reduction in the system impact in the case of using this scenario if it is compared with the current situation.

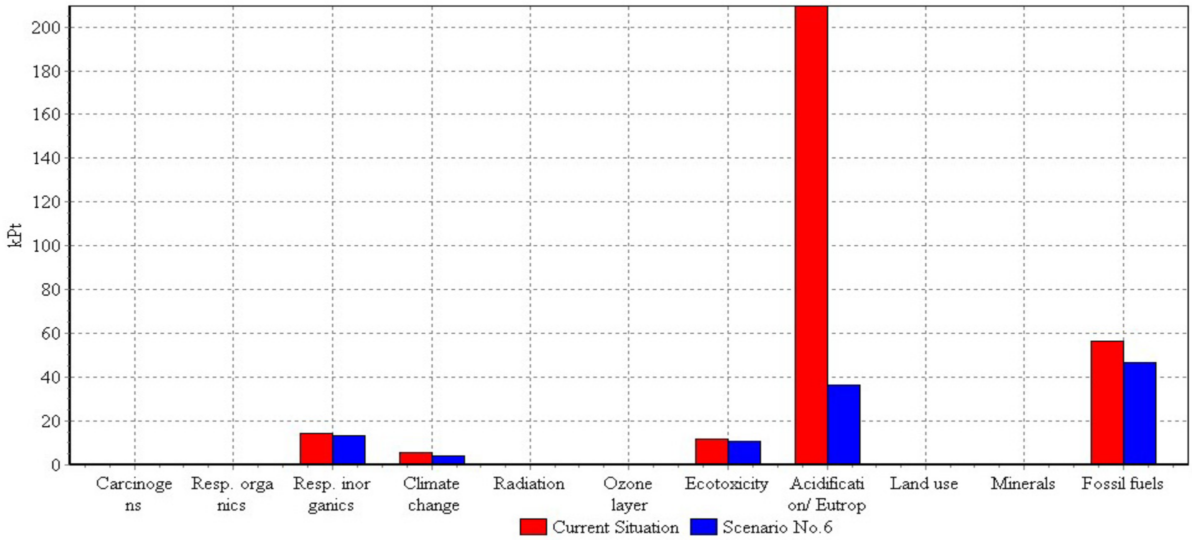

Figure 5.12: comparison between the impacts of scenario No.6 and the current situation on the different impact categories.

5.2.2 The best scenario

The best scenario can be defined as the scenario which has the lowest environmental impact. The use of this definition can led to the conclusion that scenario No. 6 is the best scenario as shown in Figure 5.13.

However, there is two concepts has to be taken into consideration in addition to the environmental impact in order to define the better scenario in a correct way, those concepts are:

- The adaptability of the scenario: some scenarios could be technically difficult to be implemented.
- The integration of the scenarios: in some cases more than one scenario can be adapted together because there is no conflict between those scenarios.

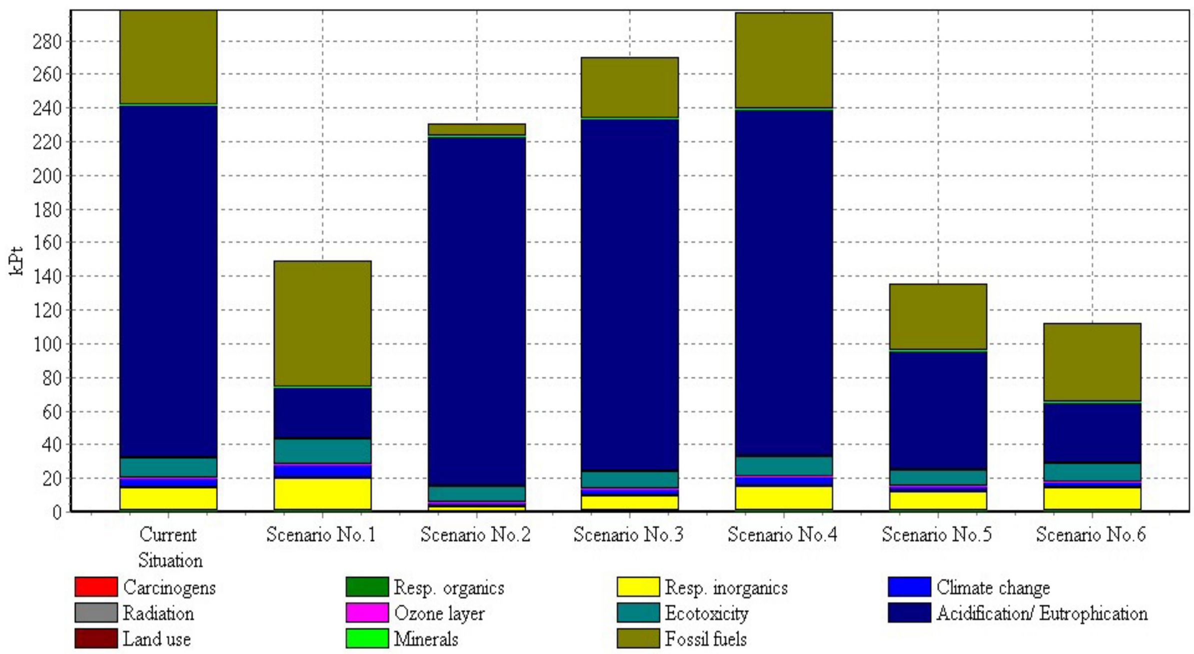

Figure 5.13: Total environmental impacts of the current situation and the proposed scenarios.

Taking the two aforementioned concepts into consideration led to the following remarks:

- Scenario No.2 (green energy) is technically difficult to be implemented because it requires changing all the pumps in the system which is very difficult at least in the short run.

- Scenario No.5 (decentralized WWTPs for household wastewater) and Scenario No.6 (decentralized WWTPs for household wastewater and activated sludge for other kinds of wastewater) can't be adapted in the short run but they can be the best solutions for future improvement for the system.
- The there is no conflict between the category of "technical intervention" and the category of "better management", so a combination of two or more scenarios from the two categories could be possible for more improvement of the system.
- Also there is no conflict between the category of "paradigm shift" and the category of "better management", so a combination of two or more scenarios from the two categories could be possible for more improvement of the system.

According to the aforementioned remarks, two solutions could be recommended for improving the total performance of Alexandria's urban water system. The first solution is to decrease the losses in the distribution network and to decrease the water consumption (scenario No. 3), in addition to the use of the activated sludge technology with nutrients removal units (scenario No. 1), in this case also scenario No. 4 (treatment of untreated wastewater) can be used although it showed small reduction in the impact but as the scenario No.1 will improve the treatment so using scenario No. 4 can show higher reduction in the

impact than what it showed before. This solution can decrease the total impact of the system by about 66.4%.

The second solution is using the same combination of scenarios that is mentioned in the first solution, the only difference is using scenario No.6 instead of using scenario No.1. And this solution could be suitable as a future strategy for improving the system because it is difficult to be implemented in the short run. This solution can decrease the total impact of the system by about 76.6%. Figure 5.14 shows the environmental impacts of the current situation and the two solutions.

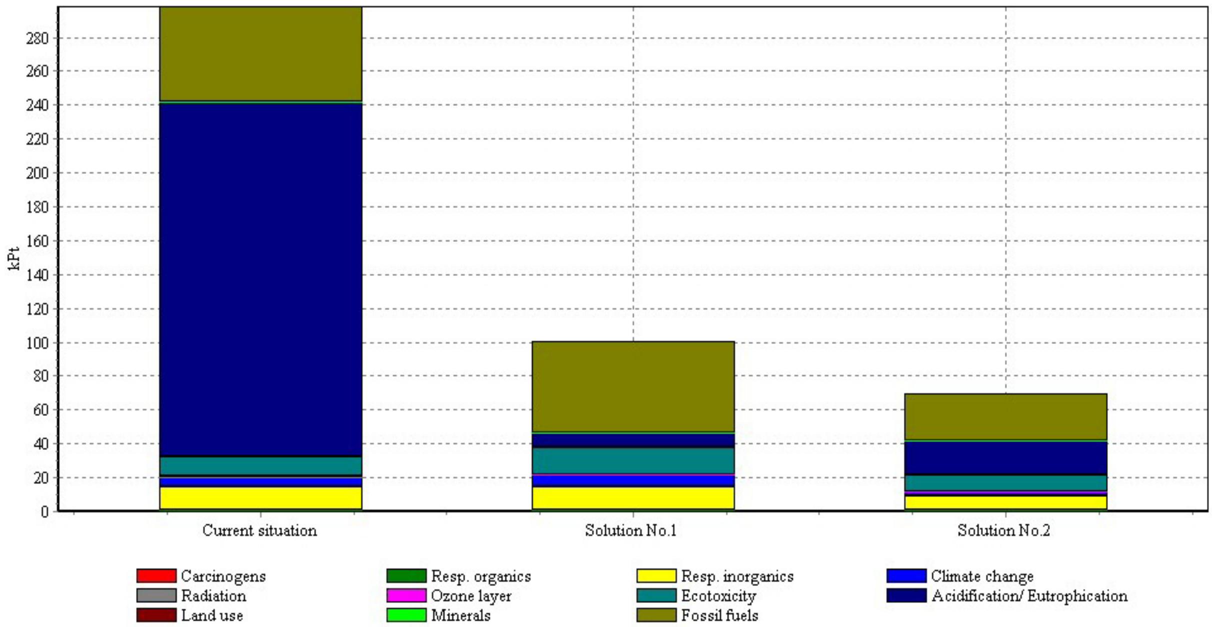

Figure 5.14: The environmental impacts of the two combinations of the scenarios and the current situation.

5.3 Recommendations for decision makers

The local government with the assistance of the city alliance have developed a city development strategy (CDS) in order to tackle the long term development of the city. As a part of the CDS, comprehensive strategic development plan for Lake Mariout zone have been developed with the aim of the rehabilitation of the lake, one of the programs of this strategy is to reduce the wastewater pollution from municipal and industrial sources by improving the performance of the wastewater treatment plants discharging into the lake, this program will partly help in improving the urban water system of the city. In addition, the local government developed the urban upgrading strategy which will help in improving the urban water infrastructures in a thirty squatter settlements within the city (AGPP, 2006).

The main plan that was developed by the local government concerning the urban water system is to upgrade the east WWTP and the west WWTP to be secondary treatment instead of primary

treatment currently. So, obviously the local government concentrated only on the WWTPs, but there are no plans for the other compartments of the system due to the perception that the wastewater system is the only problematic part in Alexandria's urban water system. In contrary, this research focused on all the compartments of the system not only the WWTPs. So, although the WWTPs showed the highest contribution to the total impact, but it was recommended that the system has to be improved in an integrated way.

There are some similarities between the plan suggested by the local government and the recommended solutions suggested by this research. Both of them suggested using the activated sludge technology with nutrients removal units instead of the current primary treatment plants. Moreover, both of them recommended the use of the treated wastewater in the irrigation. Nevertheless, this research concluded that the paradigm shift by the use of decentralized WWTPs for the household wastewater in addition to the use of the activated sludge for the other kinds of wastewater is the best strategy for the future improvement of the system.

There are also some differences between the plan suggested by the local government and the recommended solutions suggested by this research. The main difference is that the local government taken into account only the WWTPs but they ignored the other compartment of the system, whilst the results of this research revealed that the other compartments of the system has significant contribution to the total impact of the system, especially the water treatment plants and the water transportation where huge amounts of energy is consumed in both of them, so this research recommended that the use of the green energy could be very helpful in decreasing the impact of the system.

In addition, the local government ignored the losses in the distribution network which lead to waste the resources and it increases the impact of the system because the highest the losses the highest the amount of the water that has to be produced for the same number of users. On the other hand, this research recommended the reduction of the losses as one of the important ways for improving the system. The losses in the distribution network could be reduced by adequate maintenance. The reduction of these losses will significantly decrease the impact of the system and it will also save the resources.

One of the important measures that were proposed by this research is the treatment of the currently untreated wastewater (with upgraded treatment system) especially the industrial wastewater that are discharged to Lake Mariout and the Municipal wastewater that discharged to the sea without any treatment. In contrary, the plan of the local government didn't include this wastewater.

In general this research recommends for the decision makers to deal with the system in an integrated way for better management for the system.

5.4 Data Reliability

Most of the data have been collected from Alexandria's drinking water company and Wastewater Company as have been mentioned earlier in chapter 3. The unavailable data are reasonably assumed or collected from literature. The data are critically reviewed and the following remarks were found.

i. Although the data concerning the wastewater characteristics at the influent and the effluent of the WWTPs were collected from Alexandria's wastewater company, but the nutrients concentrations in the influent of the west WWTP, Eskan Mubarak WWTP, and Hanoville WWTP showed very low values if it is compared with the known average in the literature, and even these concentrations are very low if it is compared with the ones in the east WWTP. There is no known reason for this difference, and it is not possible to judge if the data collected from the wastewater company is accurate or not.

ii. Although the east WWTP and the west WWTP use the same treatment system but the energy consumption (in the treatment process only) by the west WWTP is almost twice the consumption of the east WWTP.

iii. The data of the water treatment plants showed high consistency between all the water treatment plants, which could be an indicator for the accuracy of the data.

iv. The data collected from the literature are from similar systems as the ones used in Alexandria, but still there are differences even if it is minor differences. In some cases data for systems that do not exist in Alexandria (such as the paradigm shift) are assumed to be the same if it is implemented in Alexandria which is not totally true.

Most of the aforementioned remarks on the data could be possible sources for the unreliability of the data. However, in this research the data used are collected from the most trustable sources in order to increase the reliability of the data as much as possible which reflects on the reliability of the results of the research.

5.5 The integrated approach advantages and disadvantages

The integrated approach was used in this research in order to assess the whole system in an integrated way instead of assessing each compartment separately. The use of such approach has its advantages and its disadvantages.

The main advantage of using the integrated approach is to identify the most problematic compartment in the system to pay more attention to this compartment when improving the system, while the assessment of each compartment separately could waste the time, the

efforts, and may be the money in improving part of the system which will not affect much in the total performance of the system.

On the other hand, the integrated approach could be time consuming and more complex than non-integrated approach which could lead to possible mistakes in the assessment process. Also the assessment of each compartment separately could lead to more detailed assessment of each compartment and the assessment by this way can go more in depth in each compartment, which is not easy (mostly not done) in the integrated approach.

In order to get more accurate results and to take the advantages of the two approaches, it is recommended that detailed studies by different researches for the compartments of the system could be carried out separately, and then the results of these studies could be incorporated in one study for the assessment of the whole system.

6 Conclusions, Recommendations, and Limitations

6.1 Conclusions

Based on the results of this research and within its limitations, the following conclusions can be drawn:

i. The total environmental impact of Alexandria's urban water system is about 298,000 eco-points per day. The impact per cubic meter differs based on the pathways of the water. One pathway could be water treatment, water transportation, wastewater treatment, and wastewater transportation, this pathway results an average impact of about 0.208 eco-points/m^3. Another pathway is when the wastewater ends up in the water bodies without treatment; the average impact of this pathway is about 0.317 eco-points/m^3.

ii. The wastewater treatment has the highest impact in Alexandria's urban water system which is about 68 % of the total impact of the system; this impact resulted mainly from the discharge of nutrients-rich effluent into the water bodies due to the low removal efficiency of the nutrients in the wastewater treatment plants.

iii. The water treatment plants showed less impact than the wastewater treatment plants and their impact was about 18 % of the total impact of the system. The main driving force behind the environmental impact of the water treatment plants was the use of fossil fuel-generated energy (mainly in pumping). The chemicals use showed significant impact but very low if it is compared with the energy use.

iv. A relatively high percentage of the total impact of Alexandria's urban water system was due to the discharge of untreated wastewater into the water bodies (7% of the total impact of the system).

v. The impact of water transportation and wastewater transportation was significant but quite lower than the other compartments of the system. And their impact was mainly due to energy use.

vi. Improving the system could be by the technical intervention, or by improving the management of the system, or by the paradigm shift.

vii. The technical intervention by upgrading the current wastewater treatment plants to be secondary treatment using the activated sludge and tertiary treatment decreased the total impact of the system by about 50 %.

viii. Improving the management of the system by decreasing the losses (by 25%) and by decreasing the water consumption (by 15%) could decrease the impact of the system by about 9 %.

ix. The use of green energy in the pumping could decrease the impact of the system considerably by about 23%. However, replacing all the current pumps with new ones operating with green energy is technically very difficult at least in the short run.

x. Although the significant impact of the untreated wastewater, but collecting it and treating it using the current way of treatment which is not so efficient will not help in decreasing the total environmental impact of the system. However, the treatment of this water will be helpful if the current treatment efficiency is improved.

xi. The paradigm shift towards new technique in urban water systems could be very effective in decreasing the environmental impact. The use of urine separation system with decentralized treatment in Alexandria instead of the current system in addition to the use of activated sludge for treating industrial wastewater decreased the total impact with about 62 %. However, this system will be more suitable for the future.

xii. Combining the technical intervention (the use of activated sludge) and the better management for the system (decreasing the losses in the distribution network, decreasing the water consumption, and collecting and treating the untreated wastewater) decreased the total impact of the system by about 66.4%. The same combination but with the use of paradigm shift instead of technical intervention decreased the total impact with about 77 %.

xiii. The integrated approach in assessing the whole system could identify the most problematic compartment, which help in taking the right decision in improving the system. However, the non integrated approach could help in carrying out more detailed studies.

6.2 Recommendations for future research

The following issues are recommended for the future research:

i. More detailed study containing not only the environmental dimension of the system but also the economic and social dimension.

ii. Assessment of the private WWTPs (such as the ones for pre-treatment of industrial wastewater).

iii. Assessment for the construction phase and demolition phase for drawing more complete picture about the system.

iv. Detailed data about the inputs and the outputs of the system have to be used for improving the model of the system.

v. Some direct measurements could be important to increase the data reliability and hence the results reliability.

vi. A pilot system for the paradigm shift system could help in assessing it more precisely.

6.3 Limitations

The following are the main limitations of this research:

i. The construction phase and demolition phase were not considered.

ii. The impact of the pre-treatment of the industrial wastewater by the industries was not taken into consideration.

iii. The assessment method used (eco-indicator 99) has limitations especially for the impact of emissions of nutrients into the water.

iv. The characterisation factors for nutrients and COD are just rough estimation from literature and are not very precise.

v. Some of the data used are from literature and are not specific to the system under study.

vi. The impact of the heavy metals as water emissions were not taken into consideration.

vii. The impact of the losses in sewerage network wasn't taken into account.

viii. The software SimaPro has limitations related to its library and the waste scenarios.

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Annexes

Annex A: Eco-Indicator 99 Methodology.

Eco-Indicator 99 is damage oriented impact assessment method (the damage that caused by a product or a system on the environment), the method consider only three types of environmental damage and hence it provides weighing factor to them; these environmental damage types are (Goedkoop et al., 2001):

- Human health
- Ecosystem quality
- Resources

The main reason for weighing only the aforementioned types of damage is that Eco-indicator 99 considered two important requirements for the weighing step (Goedkope et al., 2001):

- The number of subjects to be weighted should be as small as possible.
- The subjects to be weighted should be easy to explain a panel

To link these three damage categories with the inventory results, the following damage models have been established by Eco-indicator 99 (Goedkoop et al., 2001):

1. Damages to Human Health are expressed as Disability Adjusted Life Years (DALY). These are supported in models developed for respiratory and carcinogenic effects, climate change, ozone layer depletion and ionizing radiation effects. In these models for Human Health, four sub-steps are used:

    a. Fate analysis, linking an emission (expressed as mass) to a temporary change in concentration,

    b. Exposure analysis, linking temporary concentration to a dose,

    c. Effect analysis, linking the dose to a number of health effects, like the number and types of cancers,

    d. Damage analysis, linking health effects to DALYs, using estimates of the number of Years Lived Disabled (YLD) and Years of Life Lost (YLL).

2. Damages to Eco-system Quality are expressed as the percentage of species that have disappeared in a certain area due to the environmental load. This definition is not as homogeneous as the one for one Human Health, thus:

    a. Eco-toxicity is expressed as the percentage of all species present in the environment living under toxic stress (PAF). Since this is not an observable damage, a rather crude conversion factor is used to translate the toxic stress into real observable damage.

    b. Acidification and eutrophication are treated as a single impact category. Here the damage to target species (vascular plants) in natural areas is modelled.

c. Land use and land transformation is based on empirical data of the occurrence of vascular plants as a function of the land-use type and the area size. Both the local damage on the occupied or transformed area as well as the regional damage on ecosystems is taken into account.

3. Resource extraction is related to a parameter that indicates the quality of the remaining mineral and fossil fuels. In both cases the extraction of the resources will result in higher energy requirements for future extraction. The general methodology of Eco-indicator 99 is shown in Figure A.1.

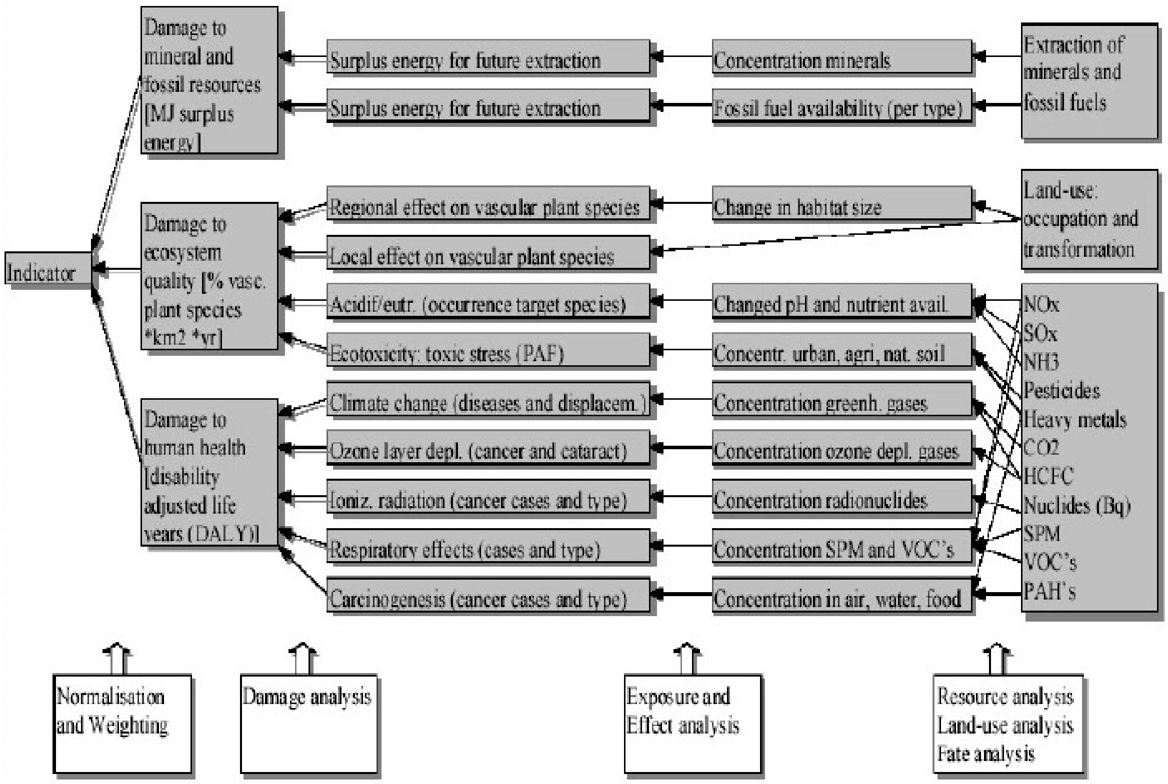

Figure A.1: Representation of the general methodology of Eco-Indicator 99 (Goedkoop et al., 2001)

Annex B: Calculations of Characterization factors of nutrients and COD.

Based on Eco-invent report No.3 (2004), the characterization factor of total nitrogen is 18.8 PDF*m2*yr / kg. While the Eco-Indicator 95 expressed the characterization factor of total nitrogen as 0.42 kg of PO_4. So:

Characterization factor of PO_4 = 18.8 / 0.42 = 44.76 PDF*m2*yr / kg.

Based on the aforementioned number and the characterization factors of Eco-Indicator 95, the following characterization factors of phosphorous and COD were calculated as follows:

- Characterization factor of total phosphorous is 3.06 kg PO_4 (Eco-Indicator 95), so characterization factor of P_{total} = 3.06 kg PO_4 = 3.06 * 44.76 = 136.97 PDF*m2*yr / kg

- Characterization factor of COD is 0.022 kg PO_4 (Eco-Indicator 95), so characterization factor of COD = 0.022 * 44.76 = 0.98 PDF*m2*yr / kg

Annex C: Normalized data that are used in Scenario analysis.

1. Normalized data for Scenario No. 1 (TI-1)

The following tables show the normalized data that is used for scenario No.1 (TI-1), the data is for the east WWTP and the west WWTP.

Table C.1: Normalized data for the East WWTP for scenario No.1 (TI-1) (Teng, 2006).

Item	Value	Item	Value
Influent Water borne pollutants	(Kg/m3)	**Effluent Water borne pollutants**	(Kg/m3)
T.S.S	0.228042	T.S.S	0.011402
BOD	0.175798	BOD	0.00879
COD	0.482934	COD	0.024147
NO3	0.038400	NO3	0.00192
PO4	0.026200	PO4	0.00131
Energy consumption (kWh/m3):		**Air borne Emissions (kg/m3):**	
Process energy	0.37	Carbon dioxide(CO2)	0.642302
Pumping energy	0	**Solid Emissions (kg/m3)**	
Total energy	0.37	Screenings	0.000123
Transportation (tkm/m3)		Grits	0.000809
Transportation of sludge	0	Sludge	0.21664
Transport of FeCl3	0.02	Total (Screenings+Grits+Sludge)	0.217572
		FeCl3 (kg/m^3)	0.08

Table C. 2: Normalized data for the west WWTP for scenario No.1 (TI-1) (Teng, 2006).

Item	Value	Item	Value
Influent Water borne pollutants	(Kg/m3)	**Effluent Water borne pollutants**	(Kg/m3)
T.S.S	0.951722	T.S.S	0.047586
BOD	0.469030	BOD	0.023452
COD	1.154424	COD	0.057721
NO3	0.011500	NO3	0.000575
PO4	0.008233	PO4	0.000412
Energy consumption (kWh/m3):		**Air borne Emissions (kg/m3):**	
Process energy	0.3700	Carbon dioxide(CO2)	1.535384
Pumping energy	0.068259	**Polymers (kg/m3)**	0.001513
Dewatering energy	0.049982	**FeCl3 (kg/m3)**	0.08
Total energy	0.488241	**Solid Emissions (kg/m3)**	
Transportation (tkm/m3)		Screenings	0.000337
Transportation of sludge	0.027124	Grits	0.001378
Transportation of polymers	0.000378	Sludge	0.904136
Transport of FeCl3	0.02	Total (Screenings+Grits+Sludge)	0.905851

2. Normalized data for scenario No.5 (PS-1)

The data used in scenario No.5 (PS-1) are shown in Table C.3.

Table C. 3: Normalized data for the west WWTP for scenario No.1 (TI-1) (Teng, 2006).

Item	Value	Item	Value
Energy consumption (kWh/m3)	0.134823	**Emissions to water (kg/m^3)**	
Emissions to air (kg/m^3)		COD	1.57E-06
CO_2	0.104892	BOD	0.018787
SO_2	0.000205	N	0.006067
No_x	0.00174	P	0.002544
Hydrocarbons	0.000278	**Avoided products (kg/m^3)**	
CO	0.000401	N-Fertilizer	0.084344
Particulates	0.000135	P-Fertilizer	0.022896

A schematic of the system used in scenario No. 5 (PS-1) is shown in Figure C.1.

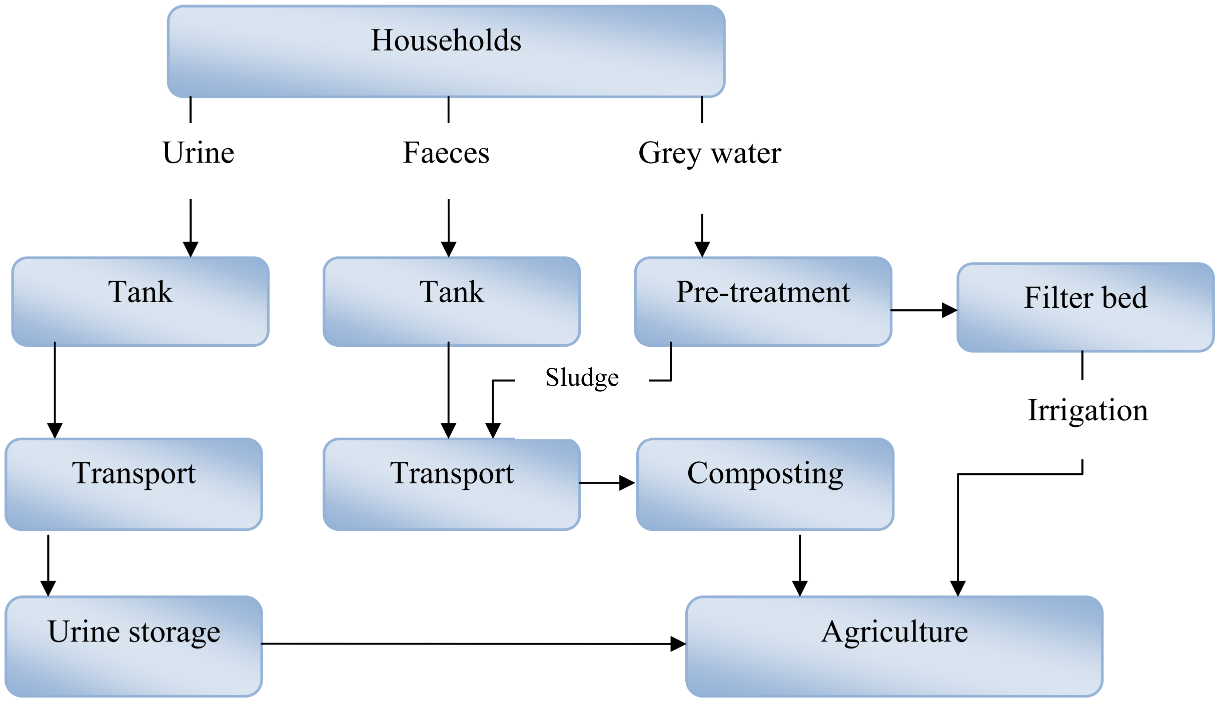

Figure C.1: Schematic of the system used in scenario No.5 (Tillman et al., 1998).

Annex D: The Environmental impacts of the analyzed compartments

1. Environmental impact of water treatment plants.

Table D.1: Environmental impacts of Bab Sharky water treatment plant (eco-points/m^3).

Impact category	Unit	Total	Clarification	Clean water pumping	Filtration	Raw water pumping
Carcinogens	Pt/m^3	0.000172	3.72E-05	6.55E-05	9.32E-07	6.86E-05
Resp. organics	Pt/m^3	1.35E-05	2.09E-06	5.55E-06	7.85E-08	5.78E-06
Resp. inorganics	Pt/m^3	0.00408	0.00113	0.00144	2.01E-05	0.00148
Climate change	Pt/m^3	0.000919	0.000152	0.000371	5.31E-06	0.000391
Radiation	Pt/m^3	0	0	0	0	0
Ozone layer	Pt/m^3	3.75E-06	4.68E-07	1.56E-06	2.31E-08	1.7E-06
Ecotoxicity	Pt/m^3	0.000767	0.000101	0.000317	4.68E-06	0.000344
Acidification/ Eutrophication	Pt/m^3	0.000466	0.000125	0.000168	2.32E-06	0.000171
Land use	Pt/m^3	0	0	0	0	0
Minerals	Pt/m^3	4.52E-09	2.76E-09	1.76E-09	0	0
Fossil fuels	Pt/m^3	0.0148	0.00199	0.00614	8.96E-05	0.00659
Total	Pt/m^3	0.0212	0.00354	0.00851	0.000123	0.00906

Table D.2: Environmental impacts of El-Ma'amoura water treatment plant (eco-points/m^3).

Impact category	Unit	Total	Clarification	Clean water pumping	Filtration	Raw water pumping
Carcinogens	Pt/m^3	0.000171	2.78E-05	6.99E-05	1.38E-06	7.23E-05
Resp. organics	Pt/m^3	1.39E-05	1.77E-06	5.92E-06	1.17E-07	6.09E-06
Resp. inorganics	Pt/m^3	0.00392	0.00078	0.00155	3.06E-05	0.00156
Climate change	Pt/m^3	0.00094	0.000125	0.000395	7.82E-06	0.000412
Radiation	Pt/m^3	0	0	0	0	0
Ozone layer	Pt/m^3	3.91E-06	4.39E-07	1.65E-06	3.27E-08	1.79E-06
Ecotoxicity	Pt/m^3	0.000796	9.27E-05	0.000334	6.61E-06	0.000363
Acidification/ Eutrophication	Pt/m^3	0.000451	8.68E-05	0.000181	3.57E-06	0.00018
Land use	Pt/m^3	0	0	0	0	0
Minerals	Pt/m^3	3.93E-09	1.5E-09	2.39E-09	4.72E-11	0
Fossil fuels	Pt/m^3	0.0154	0.0018	0.0065	0.000128	0.00695
Total	Pt/m^3	0.0217	0.00291	0.00904	0.000179	0.00954

Table D.3: Environmental impacts of El-Manshia water treatment plant (eco-points/m^3).

Impact category	Unit	Total	Clarification	Clean water pumping	Filtration	Raw water pumping
Carcinogens	Pt/m^3	0.000207	3.89E-05	8.15E-05	1.2E-06	8.55E-05
Resp. organics	Pt/m^3	1.65E-05	2.31E-06	6.9E-06	1.02E-07	7.2E-06
Resp. inorganics	Pt/m^3	0.00481	0.00114	0.0018	2.65E-05	0.00185
Climate change	Pt/m^3	0.00112	0.000166	0.000462	6.82E-06	0.000487
Radiation	Pt/m^3	0	0	0	0	0
Ozone layer	Pt/m^3	4.64E-06	5.48E-07	1.95E-06	2.88E-08	2.11E-06
Ecotoxicity	Pt/m^3	0.000946	0.000117	0.000394	5.82E-06	0.000429
Acidification/ Eutrophication	Pt/m^3	0.000551	0.000126	0.000209	3.08E-06	0.000213
Land use	Pt/m^3	0	0	0	0	0
Minerals	Pt/m^3	4.63E-09	2.45E-09	2.15E-09	3.17E-11	0
Fossil fuels	Pt/m^3	0.0182	0.00228	0.00764	0.000113	0.00821
Total	Pt/m^3	0.0259	0.00388	0.0106	0.000156	0.0113

Table D.4: Environmental impacts of El-Nozha water treatment plant (eco-points/m^3).

Impact category	Unit	Total	Clarification	Clean water pumping	Filtration
Carcinogens	Pt/m^3	0.000103	2.45E-05	7.62E-05	2.12E-06
Resp. organics	Pt/m^3	8.13E-06	1.51E-06	6.43E-06	1.79E-07
Resp. inorganics	Pt/m^3	0.00244	0.000729	0.00166	4.63E-05
Climate change	Pt/m^3	0.00055	0.000105	0.000433	1.21E-05
Radiation	Pt/m^3	0	0	0	0
Ozone layer	Pt/m^3	2.22E-06	3.19E-07	1.85E-06	5.16E-08
Ecotoxicity	Pt/m^3	0.000453	6.77E-05	0.000375	1.05E-05
Acidification/ Eutrophication	Pt/m^3	0.00028	8.19E-05	0.000193	5.37E-06
Land use	Pt/m^3	0	0	0	0
Minerals	Pt/m^3	3.85E-09	2.78E-09	1.04E-09	2.91E-11
Fossil fuels	Pt/m^3	0.0088	0.00137	0.00723	0.000201
Total	Pt/m^3	0.0126	0.00238	0.00998	0.000278

Table D.5: Environmental impacts of El-Seiouf water treatment plant (eco-points/m^3).

Impact category	Unit	Total	Clarification	Clean water pumping	Filtration	Raw water pumping
Carcinogens	Pt/m^3	0.000167	3.12E-05	6.53E-05	1.58E-06	6.86E-05
Resp. organics	Pt/m^3	1.32E-05	1.78E-06	5.53E-06	1.34E-07	5.78E-06
Resp. inorganics	Pt/m^3	0.00388	0.00092	0.00144	3.48E-05	0.00148
Climate change	Pt/m^3	0.000901	0.000131	0.00037	8.95E-06	0.000391
Radiation	Pt/m^3	0	0	0	0	0
Ozone layer	Pt/m^3	3.74E-06	4.4E-07	1.56E-06	3.78E-08	1.7E-06
Ecotoxicity	Pt/m^3	0.000763	9.48E-05	0.000316	7.64E-06	0.000344
Acidification/ Eutrophication	Pt/m^3	0.000443	0.000101	0.000167	4.04E-06	0.000171
Land use	Pt/m^3	0	0	0	0	0
Minerals	Pt/m^3	3.01E-09	1.3E-09	1.67E-09	4.03E-11	0
Fossil fuels	Pt/m^3	0.0147	0.00182	0.00613	0.000148	0.00659
Total	Pt/m^3	0.0208	0.00309	0.0085	0.000205	0.00905

Table D.6: Environmental impacts of Forn El-Garya water treatment plant (eco-points/m^3).

Impact category	Unit	Total	Clarification	Clean water pumping	Filtration
Carcinogens	Pt/m^3	0.000106	3.72E-05	6.81E-05	6.78E-07
Resp. organics	Pt/m^3	7.59E-06	1.78E-06	5.76E-06	5.73E-08
Resp. inorganics	Pt/m^3	0.00272	0.00121	0.00149	1.48E-05
Climate change	Pt/m^3	0.000526	0.000135	0.000387	3.85E-06
Radiation	Pt/m^3	0	0	0	0
Ozone layer	Pt/m^3	2.02E-06	3.57E-07	1.65E-06	1.64E-08
Ecotoxicity	Pt/m^3	0.000419	8.12E-05	0.000334	3.33E-06
Acidification/ Eutrophication	Pt/m^3	0.000307	0.000132	0.000173	1.72E-06
Land use	Pt/m^3	0	0	0	0
Minerals	Pt/m^3	4.01E-09	2.91E-09	1.08E-09	1.08E-11
Fossil fuels	Pt/m^3	0.0081	0.00159	0.00645	6.42E-05
Total	Pt/m^3	0.0122	0.00319	0.00891	8.87E-05

Table D.7: Environmental impacts of Mariout water treatment plant (eco-points/m^3).

Impact category	Unit	Total	Clarification	Clean water pumping	Filtration	Raw water pumping
Carcinogens	Pt/m^3	0.000227	3.65E-05	9.03E-05	3.02E-06	0.000097
Resp. organics	Pt/m^3	1.84E-05	2.34E-06	7.62E-06	2.55E-07	8.17E-06
Resp. inorganics	Pt/m^3	0.00515	0.00102	0.00197	6.58E-05	0.0021
Climate change	Pt/m^3	0.00125	0.000166	0.000513	1.72E-05	0.000553
Radiation	Pt/m^3	0	0	0	0	0
Ozone layer	Pt/m^3	5.26E-06	5.86E-07	2.2E-06	7.37E-08	2.4E-06
Ecotoxicity	Pt/m^3	0.00107	0.000123	0.000446	1.49E-05	0.000487
Acidification/ Eutrophication	Pt/m^3	0.000591	0.000113	0.000228	7.62E-06	0.000242
Land use	Pt/m^3	0	0	0	0	0
Minerals	Pt/m^3	2.92E-09	1.93E-09	9.63E-10	3.22E-11	0
Fossil fuels	Pt/m^3	0.0206	0.0024	0.00859	0.000287	0.00932
Total	Pt/m^3	0.0289	0.00386	0.0118	0.000396	0.0128

2. Environmental impact of wastewater treatment plants.

Table D.8: Environmental impacts of East WWTP (eco-points/m^3).

Impact category	Unit	Total	Air-borne emissions	Energy consumption	Solid emissions	Water-borne emissions
Carcinogens	Pt/m^3	7.19E-06	0	7.12E-06	6.71E-08	0
Resp. organics	Pt/m^3	6.51E-07	0	6E-07	5.06E-08	0
Resp. inorganics	Pt/m^3	0.000165	0	0.000154	1.09E-05	0
Climate change	Pt/m^3	0.00093	0.000888	4.06E-05	1.38E-06	0
Radiation	Pt/m^3	0	0	0	0	0
Ozone layer	Pt/m^3	1.82E-07	0	1.76E-07	5.77E-09	0
Ecotoxicity	Pt/m^3	3.59E-05	0	3.57E-05	1.37E-07	0
Acidification/ Eutrophication	Pt/m^3	0.323	0	1.78E-05	2.63E-06	0.323
Land use	Pt/m^3	0	0	0	0	0
Minerals	Pt/m^3	0	0	0	0	0
Fossil fuels	Pt/m^3	0.000707	0	0.000684	2.24E-05	0
Total	Pt/m^3	0.324	0.000888	0.00094	3.75E-05	0.323

Table D.9: Environmental impacts of West WWTP (eco-points/m^3).

Impact category	Unit	Total	Air-borne emissions	Energy consumption	Solid emissions	Water-borne emissions
Carcinogens	Pt/m^3	9.44E-05	0	5.74E-05	3.33E-05	3.65E-06
Resp. organics	Pt/m^3	8.23E-06	0	4.83E-06	2.76E-06	6.38E-07
Resp. inorganics	Pt/m^3	0.00193	0	0.00124	0.00071	-1.6E-05
Climate change	Pt/m^3	0.00515	0.00466	0.000327	0.000189	-2.1E-05
Radiation	Pt/m^3	0	0	0	0	0
Ozone layer	Pt/m^3	2.35E-06	0	1.42E-06	8.09E-07	1.21E-07
Ecotoxicity	Pt/m^3	0.024	0	0.000288	0.000164	0.0236
Acidification/ Eutrophication	Pt/m^3	0.123	0	0.000143	8.23E-05	-9.9E-06
Land use	Pt/m^3	1.74E-06	0	0	1.74E-06	0
Minerals	Pt/m^3	2.16E-08	0	0	2.16E-08	0
Fossil fuels	Pt/m^3	0.00861	0	0.00551	0.00317	-7.1E-05
Total	Pt/m^3	0.163	0.00466	0.00757	0.00436	0.0235

Table D.10: Environmental impacts of Eskan Mubark WWTP (eco-points/m^3).

Impact category	Unit	Total	Air-borne emissions	Energy consumption	Solid emissions	Water-borne emissions
Carcinogens	Pt/m^3	0.00012	0	8.58E-05	3.33E-05	8.92E-07
Resp. organics	Pt/m^3	1.01E-05	0	7.23E-06	2.76E-06	1.55E-07
Resp. inorganics	Pt/m^3	0.00256	0	0.00185	0.00071	-4.4E-06
Climate change	Pt/m^3	0.00206	0.00139	0.000489	0.000189	-5.3E-06
Radiation	Pt/m^3	0	0	0	0	0
Ozone layer	Pt/m^3	2.96E-06	0	2.12E-06	8.09E-07	2.93E-08
Ecotoxicity	Pt/m^3	0.00637	0	0.000431	0.000164	0.00578
Acidification/ Eutrophication	Pt/m^3	0.089	0	0.000214	8.23E-05	-2.5E-06
Land use	Pt/m^3	1.74E-06	0	0	1.74E-06	0
Minerals	Pt/m^3	2.16E-08	0	0	2.16E-08	0
Fossil fuels	Pt/m^3	0.0114	0	0.00825	0.00317	-1.8E-05
Total	Pt/m^3	0.112	0.00139	0.0113	0.00436	0.00575

Table D.11: Environmental impacts of East WWTP (eco-points/m^3).

Impact category	Unit	Total	Air-borne emissions	Energy consumption	Solid emissions	Water-borne emissions
Carcinogens	Pt/m^3	0.000115	0	8.91E-05	2.46E-05	7.94E-07
Resp. organics	Pt/m^3	7.85E-06	0	7.51E-06	2.09E-07	1.38E-07
Resp. inorganics	Pt/m^3	0.00209	0	0.00193	0.000172	-3.9E-06
Climate change	Pt/m^3	0.00136	0.000746	0.000508	0.000113	-4.7E-06
Radiation	Pt/m^3	0	0	0	0	0
Ozone layer	Pt/m^3	2.28E-06	0	2.2E-06	4.74E-08	2.61E-08
Ecotoxicity	Pt/m^3	0.0056	0	0.000447	1.31E-05	0.00514
Acidification/ Eutrophication	Pt/m^3	0.0789	0	0.000222	0.000033	-2.2E-06
Land use	Pt/m^3	6.15E-05	0	0	6.15E-05	0
Minerals	Pt/m^3	7.63E-07	0	0	7.63E-07	0
Fossil fuels	Pt/m^3	0.00978	0	0.00856	0.00123	-1.6E-05
Total	Pt/m^3	0.098	0.000746	0.0118	0.00165	0.00511

3. Environmental impact of transportation of water and wastewater.

Table D.12: Environmental impacts of transportation of water and wastewater (eco-points/m^3).

Impact category	Unit	Wastewater transportation	Water transportation
Carcinogens	Pt/m^3	4.46E-05	5.41E-05
Resp. organics	Pt/m^3	3.76E-06	4.56E-06
Resp. inorganics	Pt/m^3	0.000964	0.00117
Climate change	Pt/m^3	0.000254	0.000308
Radiation	Pt/m^3	0	0
Ozone layer	Pt/m^3	1.1E-06	1.34E-06
Ecotoxicity	Pt/m^3	0.000224	0.000271
Acidification/ Eutrophication	Pt/m^3	0.000111	0.000135
Land use	Pt/m^3	0	0
Minerals	Pt/m^3	0	0
Fossil fuels	Pt/m^3	0.00429	0.0052
Total	Pt/m^3	0.00589	0.00714

Annex E: The SimaPro models of all the subsystems of Alexandria's urban water system.

1. Models of water treatment plants (cut off 0.6%)

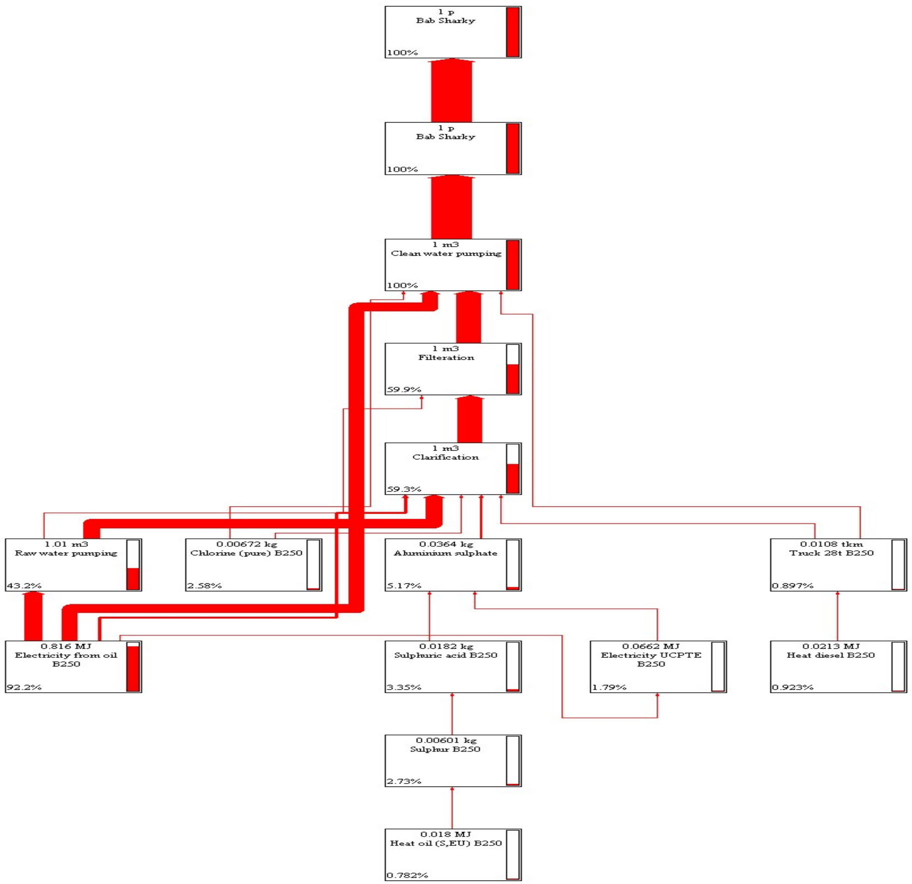

Figure E.1: Bab sharky water treatment plant model.

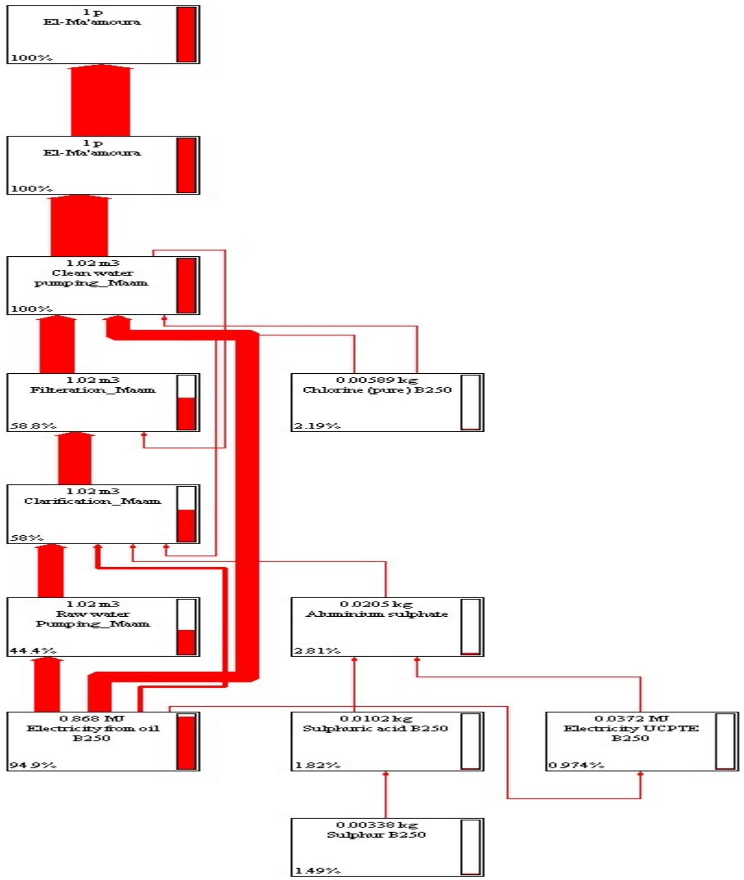

Figure E.2: El-Ma'amoura water treatment plant model.

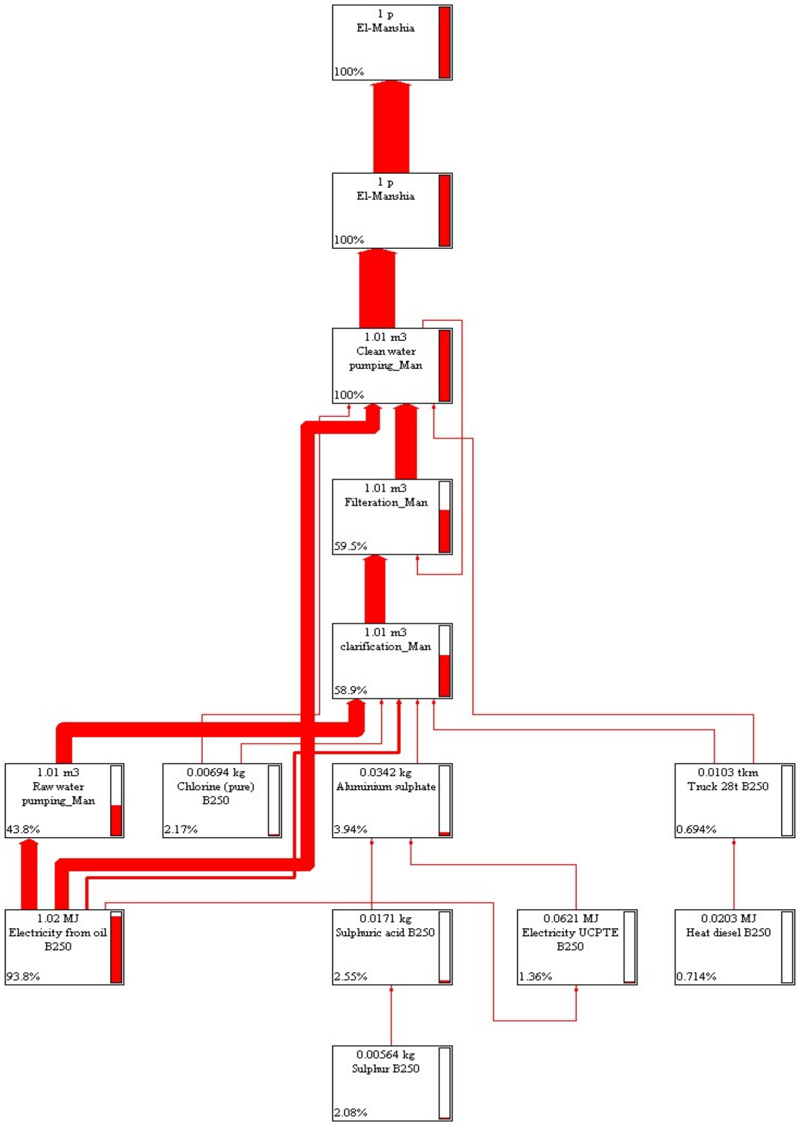

Figure E.3: El-Manshia water treatment plant model.

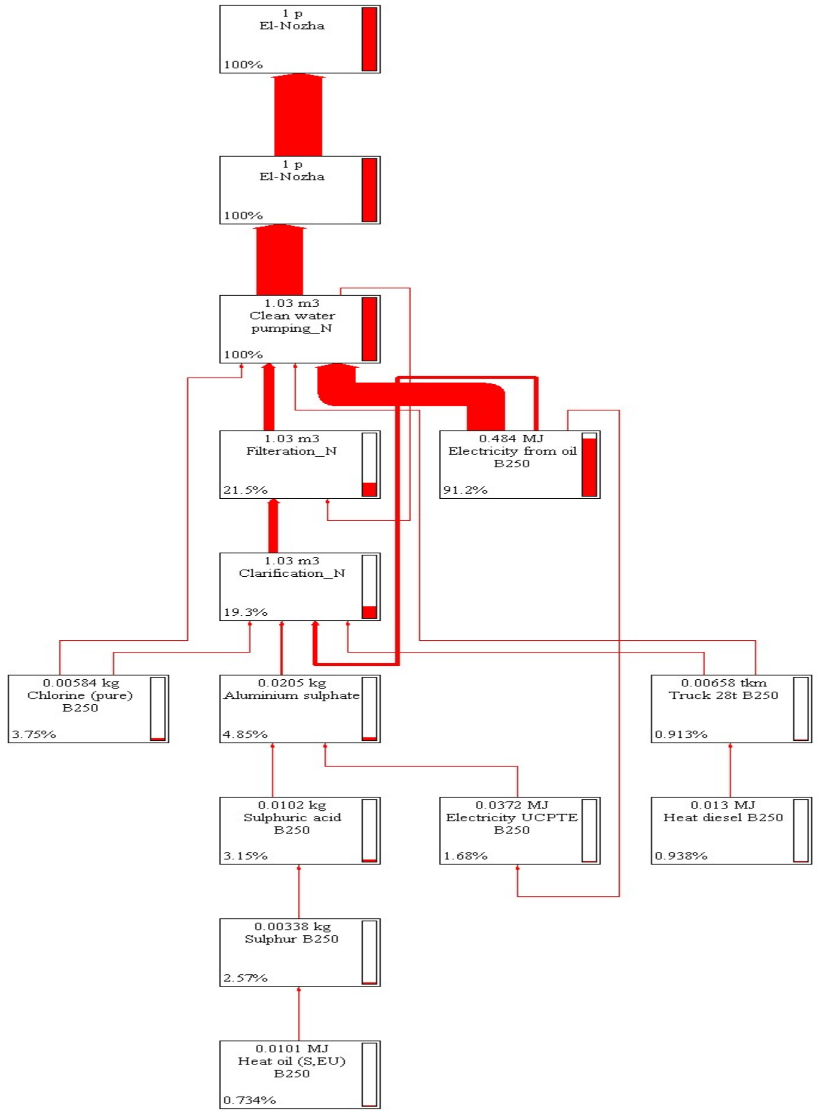

Figure E.4: El-Nozha water treatment plant model.

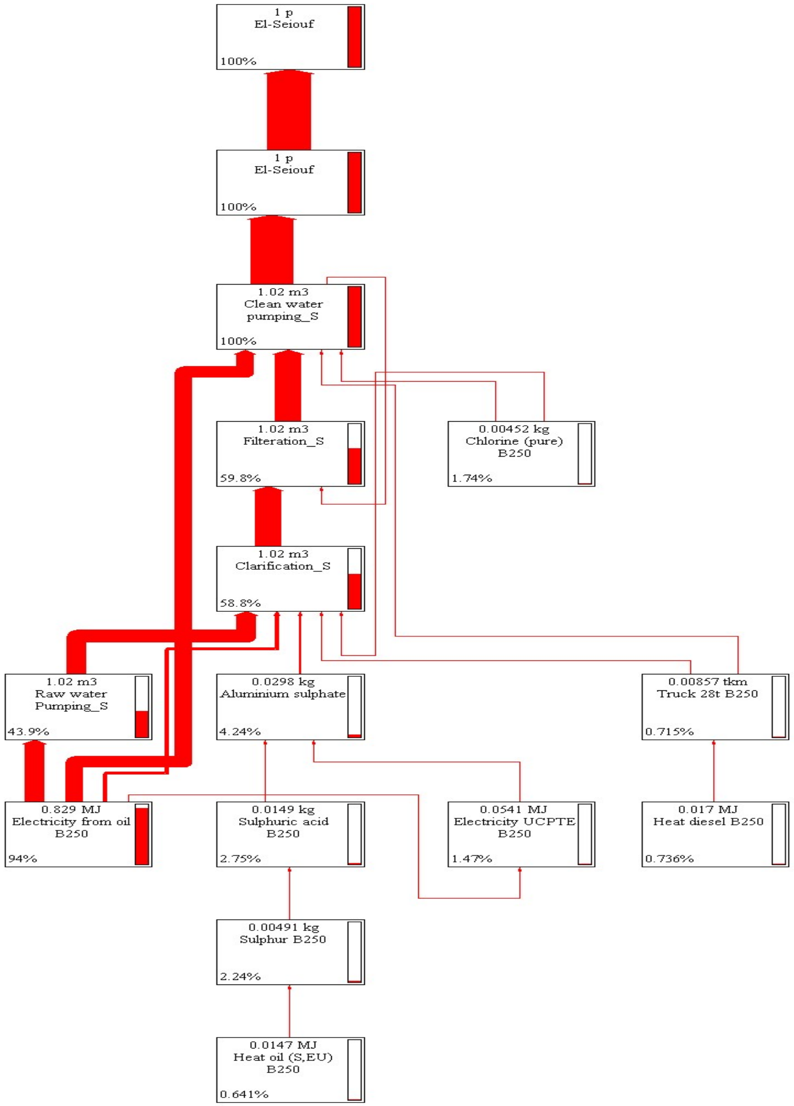

Figure E.5: El-Seiouf water treatment plant model.

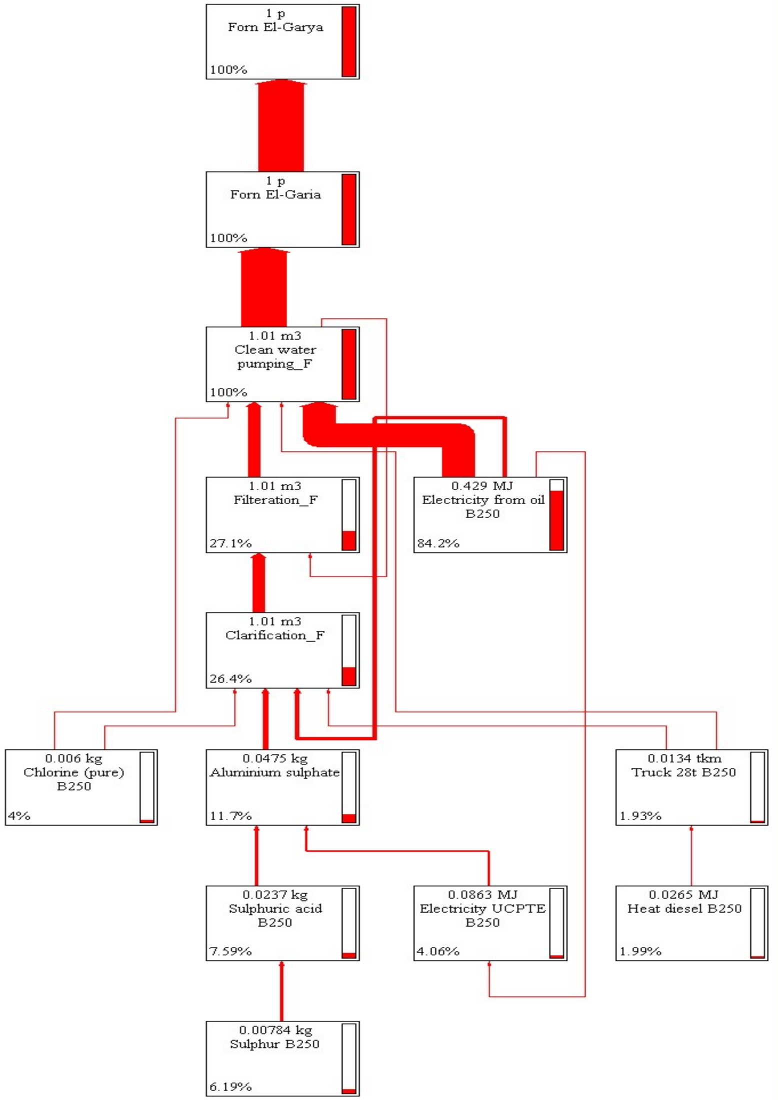

Figure E.6: Forn El-Garya water treatment plant model.

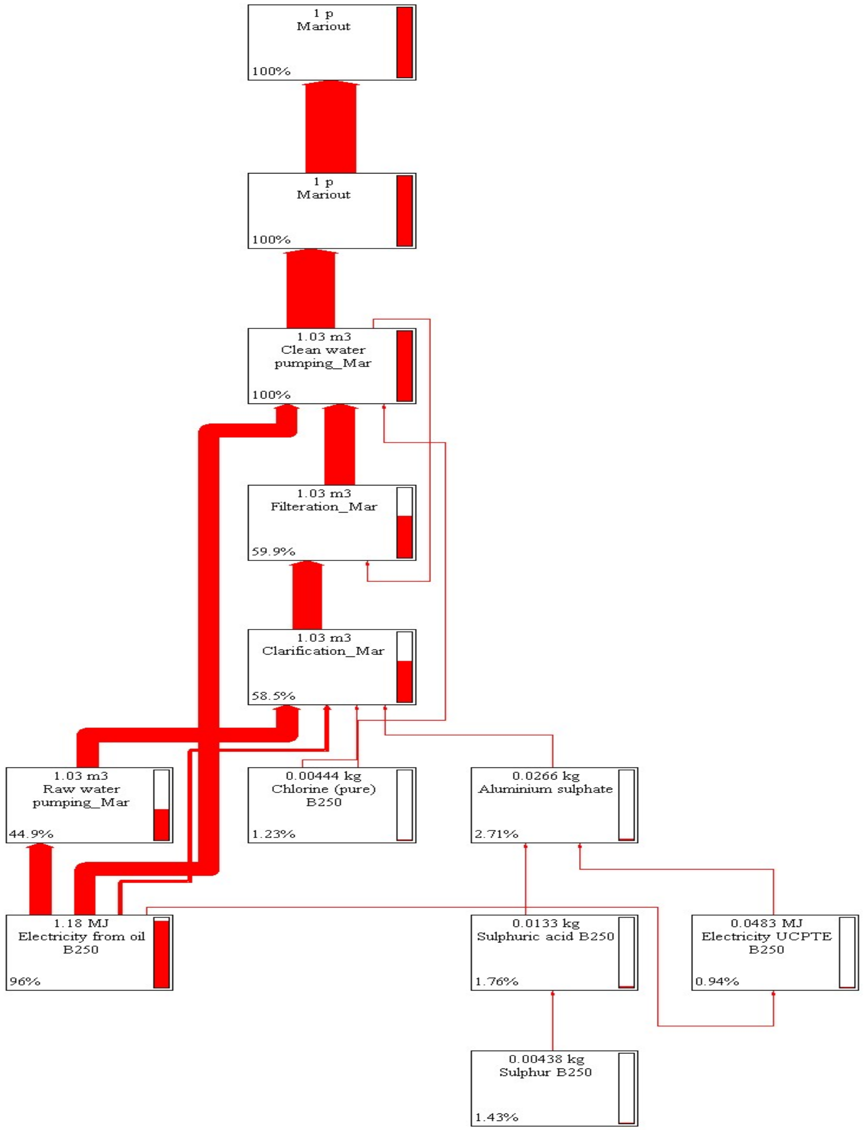

Figure E.7: Mariout water treatment plant model.

2. Models of wastewater treatment plants.

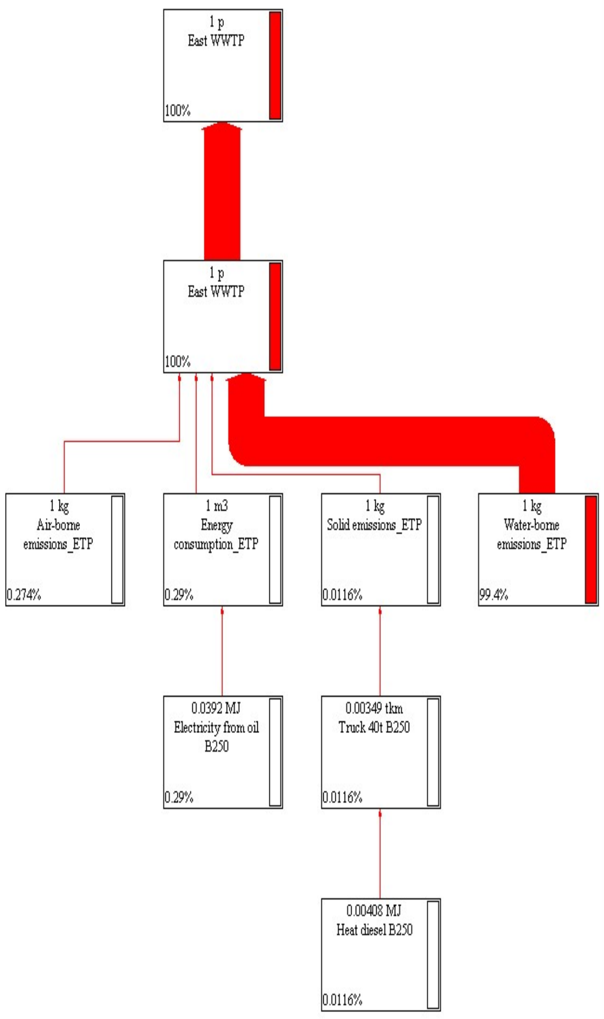

Figure E.8 East WWTP model.

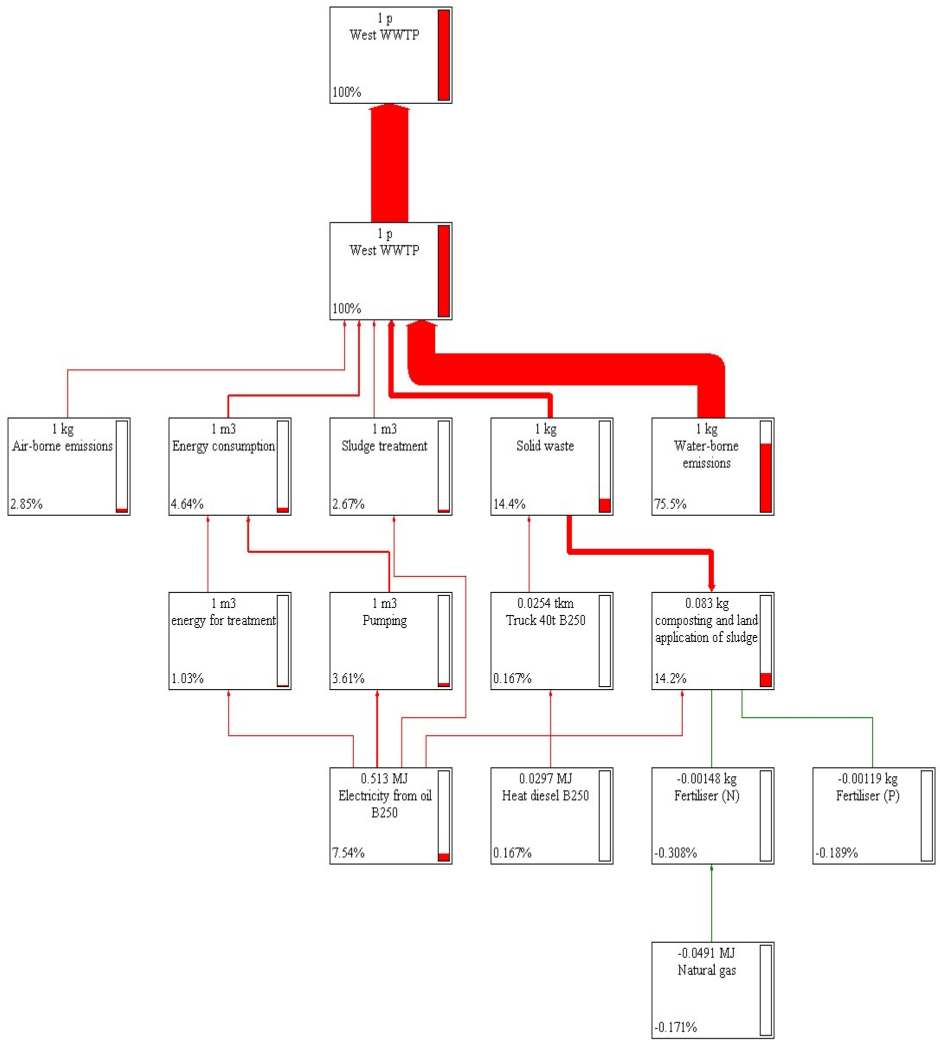

Figure E.9: West WWTP model (cut off .06%).

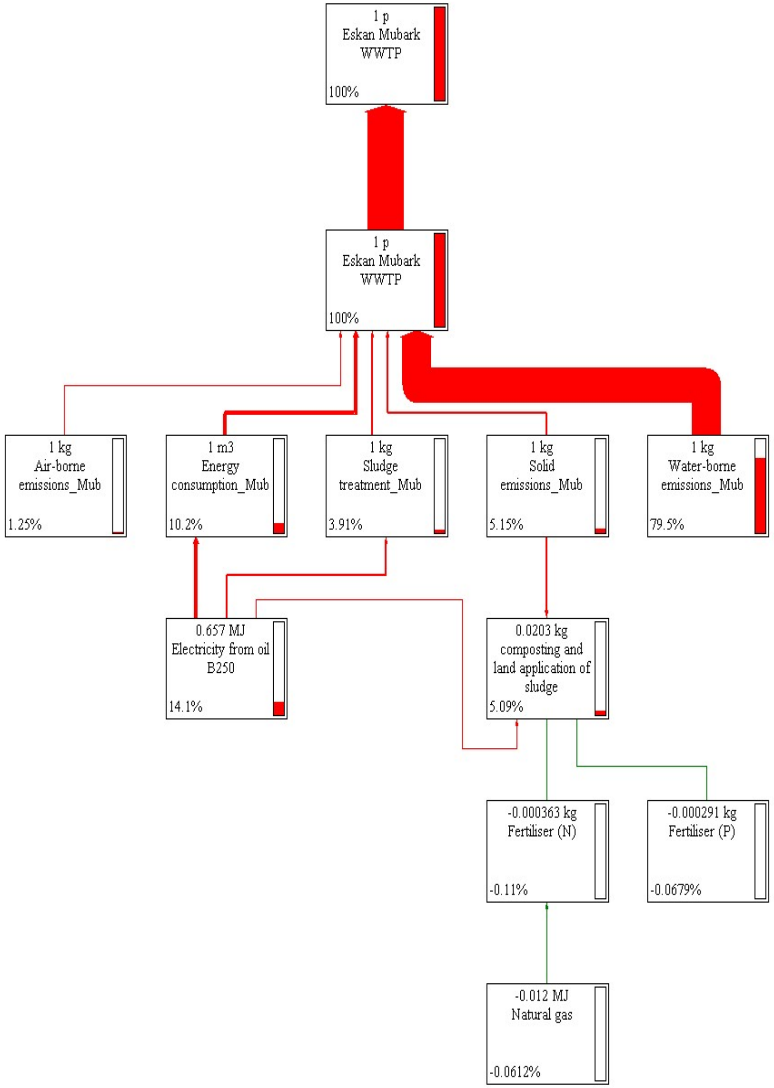

Figure E.10: Eskan Mubark WWTP model (cut off .06%).

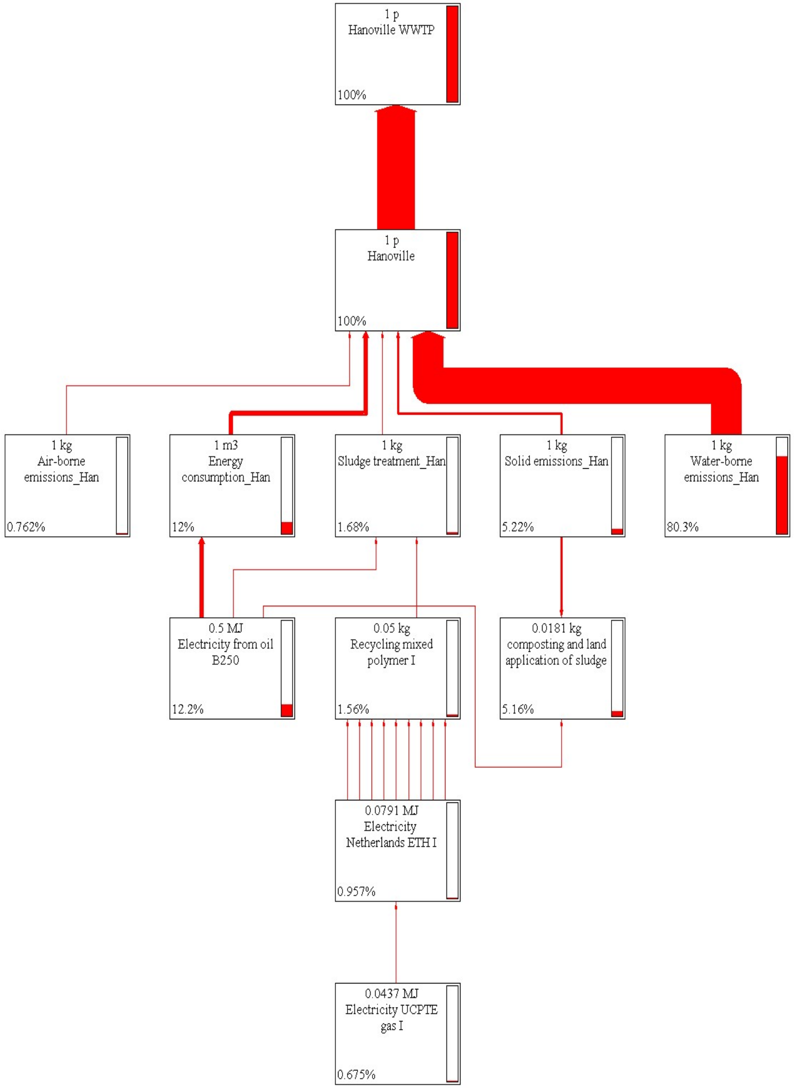

Figure E.11: Hanoville WWTP model (cut off .61%).

3. Models of transportation of water and wastewater and untreated wastewater.

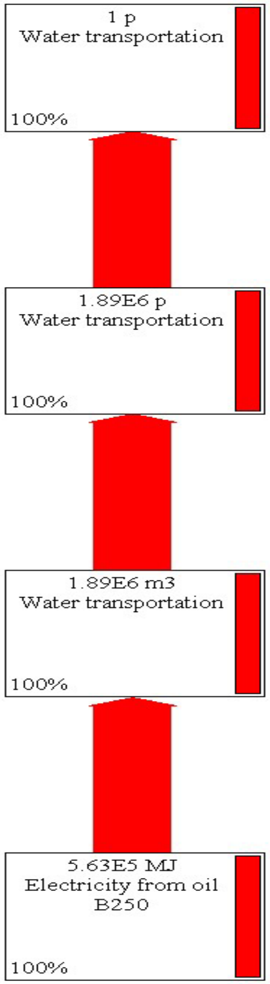

Figure E.12: Water transportation model.

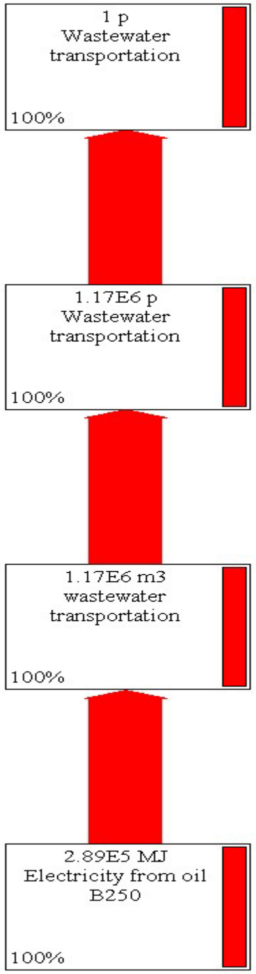

Figure E.13: Wastewater transportation model.

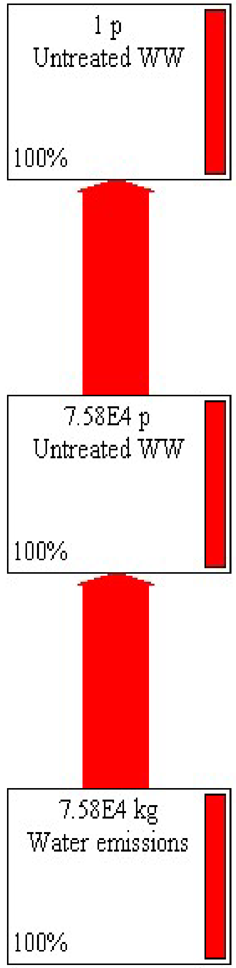

Figure E.14: Untreated wastewater model.

Annex F: Example of LCA calculations (the impact assessment phase)

In this example the impact of the air emissions of a certain product will be calculated. It is assumed that the product life cycle has the following emissions to the air:

- 1000 grams of CO_2
- 10 grams of CH_4
- 10 grams of SO_2
- 5 grams of NO_x
- 10^{-6} grams of dioxins

For calculating the impact of the above emissions the following steps are carried out:

1. Classification: Determine which of the inventory results (substances or emissions) contribute to an impact category. The following graph shows the results of this step.

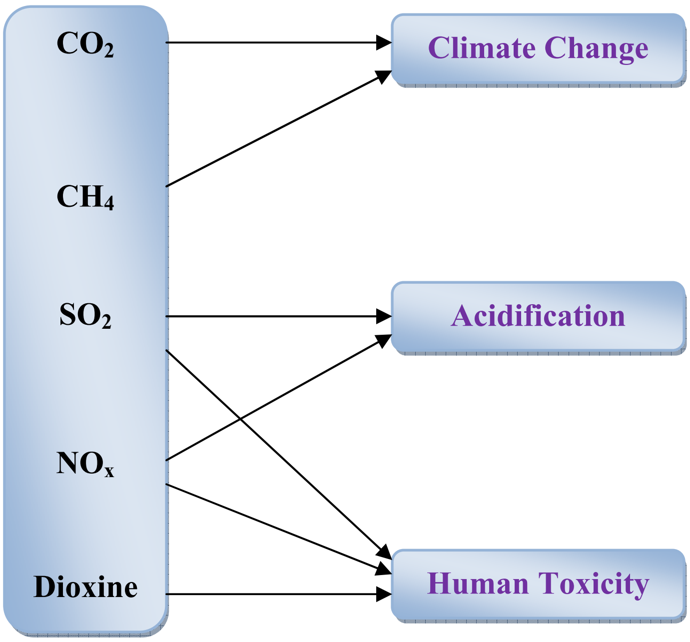

Figure F.1: Schematic of the characterization step.

2. Characterisation: Multiply the inventory results with Characterisation factors for each category to get indicator results.
3. Normalisation: dividing each indicator by a reference value (such as the average yearly load of a citizen).

   The following table shows the results of the characterisation and normalization steps.

Table F.1: The calculations of the characterization and normalization.

Inventory results	**Climate change**	**Acidification**	**Human toxicity**
1000 gr. CO_2	x 1 = 1000		
10 gr. CH_4	x 21 = 210		
10 gr. SO_2		x 1 = 10	x 1.2= 12
5 gr. NO_x		x 0.7= 3.5	x 0.78= 3.9
10^{-6} gr. dioxine			x 3.3×10^6 = 3.3
Total	1210	13.5	19.4
Reference	10.000	100	100
Normalised Impact	0.12	0.13	0.2

4. Weighing: in this step the importance of each impact category is added through adding weighing factors to each category

   Assuming that the weighing factors of the three impact categories are as follows:

   Climate change = 300
   Acidification = 300
   Human toxicity = 400

   The weighted impact (eco-points) = the weighing factors * the normalized impact. Table F.2 shows the weighted impacts.

Table F.2: The calculations of the characterization and normalization.

Inventory results	Climate change	Acidification	Human toxicity
Normalised Impact	0.12	0.13	0.2
Weighing factors	300	300	400
Weighted impact	36	39	80

The total impact of the assumed life cycle on the air emission will be the summation of the weighted impacts showed in the above table. So, the total impact = 36+39+80 = 155 eco-points.