

DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**ENVIRONMENTAL AND ECONOMIC
ASSESSMENT OF WATER REUSE
APPLICATIONS**

by
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September, 2016
İZMİR

ENVIRONMENTAL AND ECONOMIC ASSESSMENT OF WATER REUSE APPLICATIONS

**A Thesis Submitted to the
Graduate of Natural and Applied Sciences of Dokuz Eylül University
In Partial Fulfillment of the Requirements for the Degree of Master of Science
in Environmental Engineering, Environmental Engineering Program**

**by
Gökçe KARACA**

**September, 2016
İZMİR**

M.Sc THESIS EXAMINATION RESULT FORM

We have read the thesis entitled “ENVIRONMENTAL AND ECONOMIC ASSESSMENT OF WATER REUSE APPLICATIONS” completed by GÖKÇE KARACA under supervision of PROF. DR. NURDAN BÜYÜKKAMACI and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.


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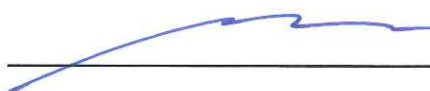
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ENVIRONMENTAL AND ECONOMIC ASSESSMENT OF WATER REUSE APPLICATIONS

ABSTRACT

A scarce water resource poses a major problem in Turkey as well as anywhere in the world. Agriculture currently accounts for maximum percentage water consumption of the world. Water reuse offers a proposed solution to this problem. The life cycle assessment (LCA) method used as decision making in wastewater reuse options in an agricultural area on the ground of choosing and comparing of proper methodology and determination of the economic and the environmental impact. The context of this thesis, wastewater treatment plant (WWTP) effluent is purified by alternative methods and intended for use in agricultural irrigation. For this purpose, LCA has been used in the assessment of these alternative methods for determining the economic and environmental impacts. These alternative methods are assessed: WWTP effluent has been treated by microfiltration and UV disinfection (Case-1), cartridge filter and ultrafiltration (Case-2), and just UV disinfection (Case-3). Two different energy sources, electric grid mix (Scenario-1) and natural gas (Scenario-2), were into consideration to determine the environmental impacts of them. Afterwards effluent of each case has evaluated to the criteria required for irrigation of sensitive crops corresponding to Turkey regulations. Evaluation of environmental and economic impacts has carried out with GaBi software.

The result of the studies revealed that, cartridge filter and ultrafiltration with electric grid mix has the biggest impact on the environment almost all impact categories. In general the most environmentally friendly solution is the most expensive one which is UV disinfection ought to requirement of replacement. Both initial and operations-maintenance costs are taken into account in the cost calculation.

Keywords: Life cycle assessment, agricultural irrigation, wastewater reuse, membrane, life cycle cost assessment

SUYUN YENİDEN KULLANIMININ ÇEVRESEL VE EKONOMİK OLARAK DEĞERLENDİRMESİ

ÖZ

Azalan su kaynakları Türkiye'de olduğu gibi tüm dünyada büyük bir problem teşkil etmektedir. Tüm Dünyada, su tüketiminin en yüksek olduğu alan tarımsal sulamadır. Suyun yeniden kullanımı bu soruna bir çözüm önermektedir. Tarım alanında atıksuların yeniden kullanım seçenekleri için uygun metodolojiyi seçme ve karşılaştırma ile ekonomik ve çevresel etkilerinin belirlenmesi açısından karar verme amacıyla yaşam döngüsü analizi (YDA) yöntemi kullanılmaktadır. Bu tez kapsamında, atıksu arıtma tesisi çıkış sularının alternatif yöntemlerle arıtılıp tarımsal sulamada kullanımı amaçlanmıştır. Bu kapsamda, YDA bu alternatif yöntemlerin ekonomik ve çevresel etkiler açısından değerlendirmesinde kullanılmıştır. Bu alternatif yöntemler şu şekilde belirlenmiştir: mikrofiltrasyon ve UV dezenfeksiyon (Örnek durum-1), kartuş filtre ve ultrafiltrasyon (Örnek durum-2) ve sadece UV dezenfeksiyon (Örnek durum-3). Çevresel etkilerini belirlemek için, elektrik (Senaryo 1) ve doğal gaz (Senaryo 2) olmak üzere iki farklı enerji kaynağının kullanıldığı göz önüne alınmıştır. Çıkış suları kalitesi, ilgili Yönetmelikteki hassas bitkilerin sulanması için gerekli limit değerler doğrultusunda değerlendirilmiştir. Çevresel ve ekonomik etkilerin değerlendirilmesi GaBi yazılımı ile gerçekleştirilmiştir.

Elde edilen sonuçlar dikkate alındığında, elektrik kullanılan kartuş filtre ve ultrafiltrasyon senaryosu hemen tüm etki kategorilerinde en büyük etkiye sahiptir. En az çevresel etkiye sahip uygulama, aynı zamanda en maliyeti yüksek olan UV dezenfeksiyon olarak belirlenmiştir. Maliyet hesabında hem yatırım hem de işletim-bakım maliyetleri göz önüne alınmıştır.

Anahtar kelimeler: Yaşam döngüsü değerlendirmesi, tarımsal sulama, atıksuların yeniden kullanımı, membran, yaşam döngüsü maliyet analizi

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

Population growth and water demand rise worldwide to the point where available resources cannot meet the need of water anymore. Due to the lack of sufficient available water is leading the world into water scarcity which can be caused by various factors such as overgrowth of pollution, and rising demand and overuse of water.

It is estimated that at least in some world regions, water use has been growing more than twice faster than the human population. For instance, the total annual water withdrawal suffered a 6.3 fold increase, rising from less than 600 km³/year, at the beginning of the twentieth century, to more than 3800 km³/year by the beginning of the twenty-first century. The irrigation practices consume up to 70% of this withdrawal (FAO, 2013;Castro- Lopes et al., 2015).

Thus, treated wastewater is increasingly being seen as a resource rather than simply 'waste.' In this context, water reuse and reclamation is getting appreciated as a water supply of communities around the world in order to achieve efficient usage of resources, ensuring protection of the environment and human health, and improving wastewater management. A large proportion of water on earth is consists of salt water in unavailable to use and usable water has quite low compared to the percentage of seawater. Reclaimed water or recycled water (reuse water), is former wastewater (sewage) that is treated to remove solids and certain impurities, and used in sustainable landscaping irrigation or to recharge groundwater aquifers. The purpose of these processes is sustainability and water conservation, rather than discharging the treated water to surface waters such as rivers and oceans. The ability to reuse water, regardless of whether the intent is to augment water supplies or manage nutrients in treating effluent, has positive benefits that are also the key motivators for implementing reuse programs. These benefits include improved

agricultural production; reduced energy consumption associated with production, treatment, and distribution of water; and significant environmental benefits, such as reduced nutrient loads to receiving waters due to the reuse of the treated wastewater. Turkey was moderately water-stressed countries, but now it's been approaching the high water-stressed countries and estimation's been accrued that has been approaching physical water scarcity in recent years (according to world resource institute) hence the reuse of water importance and necessity are increasing with each day.

According to DSI (State Hydraulic Works of Turkey); agricultural use of water has a much bigger influence corresponding to other use of water, in the Turkey ergo in this study has been directed towards water reuse in the agricultural field. Considering other alternatives such as groundwater discharge, it is prohibited in Turkey. The reuse of water for use as potable water may cause some health problems, therefore still is under debate. Industrial usage on the other hand needs to be examined separately in every industry so it is not selected as applied.

Circumstances like water scarcity, strict legislation for wastewater treatment requires better treatment technologies which stimulates upturn the costs and energy consumption, Therefore, needs for alternative technologies occurs in addition to existing systems of wastewater treatment process. In all cases the treatment system is selected as a membrane system because the primary and secondary treatment of water reuse applications has not efficient enough to accomplished regulations of discharge, thereby advanced treatment technologies must be implemented. This technology has chosen as Membrane technology. Membrane technology term refers to a number of different filtration processes that are used to separate substances. There have many different variations and many advantages, for instance, it works without the addition of chemicals, easy and well-arranged process conductions and with a relatively low energy use.

Though water reuse strategies are intended to address the problem of water scarcity, measures have taken to solving this problem comes with the price such as

infuriating other environmental problems like human health or global warming or basic cost of the membrane itself. Hence, they must be investigated carefully. One of the methodology, alternative is life cycle assessment (LCA). The Life cycle assessment methodology has proven as its worth in the evaluation of the environmental maintainability of water systems by using a whole system approach throughout the whole life cycle, and by specifying all associated types of environmental impacts of local and global scale, since the mid 1990s. LCA allows for a better evaluation of wastewater treatment technologies in many different approaches. ISO14040 (ISO, 2006 a-b) has acknowledged LCA as a standard international tool.

A series of measures announced from The European Water Act 91/271/EEC for prevent of Waste Water Treatment Plants (WWTP) effluent effects on the environment and ecosystems. There is an environmental price to pay for obtaining the desired level of water quality such as, ecotoxicity, emissions especially from energy production. Environmental Directives of EU (European Union) are emerging to Turkey regulations due to Turkey's acceptance process of the EU. New discharge standardization for wastewater treatment plant across the country might be determined on based new regulations.

1.2 Aim and Scope of the Thesis

The aim of this study is to make a decision among different WWTP effluent polishing alternatives for the purpose of agricultural irrigation with the respect of environmental effect and economic impacts by the LCA. Purpose of irrigation of agricultural areas is recommended microfiltration continue by UV in the regulations of Turkey (Case-1). Microfiltration cannot be used alone because of the diameter of the pores; it cannot purify viruses and some bacteria. Therefore UV disinfection must be applied afterwards. Alternatively ultrafiltration has been capable of carrying out itself the function of microfiltration and UV (Case-2). UF has intended to be used with pre-filter because when used alone they may give rise to clogging problems. As

mentioned earlier, the biggest problem in water reuse is some microorganisms so investigated the effectiveness of only UV disinfection (Case-3).

3 cases and 2 scenarios were investigated in the scope of this thesis. It was assumed that, the wastewater treatment plant effluent is further treated with to the one of the following treatment techniques to the point of irrigation for sensitive crops:

- Case-1: Microfiltration and UV
- Case-2: Cartridge Filter and Ultrafiltration
- Case-3: UV

Two different scenarios have also been generated to compare the environmental impact of energy sources:

- Scenario-1: Electric Grid Mix for Turkey used as an energy source.
- Scenario-2: Natural Gas for Turkey used as an energy source.

Economic and environmental impact analysis of each technique was carried out by LCA. Gabi 6 software (Thinkstep, Germany) was used for this aim. Water reclamation operations typically are seen as expensive, therefore, the cost analysis via LCC (Life Cycle Cost) which is part of the LCA was also carried out. Necessary data information was taken from one of the largest city's wastewater treatment plants in Turkey, in 2015. Other significant information for further calculations was collected from previous articles and books on the subject as secondary data. Conjectures were achieved based on using this information. The boundary of the study was preferred as “cradle to gate” without irrigation applications to the ground. The functional unit was selected as 1 m³ of treated effluent for one year. Environmental impact assessments and cost comparisons were carried out through this functional unit and other assumptions.

CHAPTER TWO

REUSE AND LIFE CYCLE ASSESSMENT

2.1 Water Scarcity and Reuse

Anticipations suggested that Earth's population will be increasing rapidly day by day. Amount and quality of specially portable and usable water is also decreasing. Therefore, many alternative solutions emerged like efficient uses of resources, reuse water or even extreme treatment of non-conventional water sources such as sea water. Water reuse steps forward as a solution to water scarcity due to the reason of both water supply, reducing pollution by the discharge.

Turkey has an increasing agricultural production despite of located in a semi-arid region. Almost 70 percent of fresh water withdrawals are consumed by agricultural irrigation uses. Reuse solution for agricultural production in developing countries such as Turkey, is important for sustainable socioeconomic development as well as water usage for irrigation to provide food.

Reclaimed water or recycled water is treated municipal wastewater for specific water quality criteria with the intent of being used for a range of purposes such as residential-urban-recreational uses, groundwater recharge, bathing water, industrial usage, cooling water, aquaculture and drinking water production. Figure 2.1 can be used as guidance on reuse application and available reuse resources.

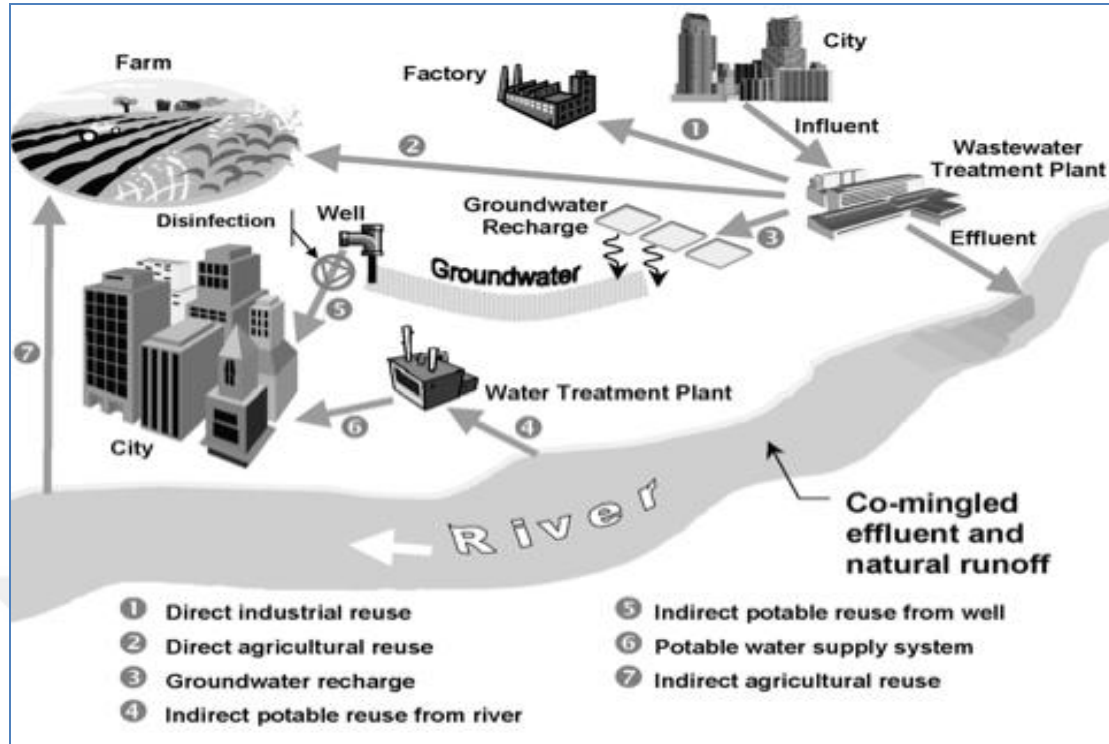


Figure 2.1 Reclaimed water as a source of water supply (Spear and Katz, 2003)

2.2 Types of Reuse Applications

There are numerous options toward expanding the use of reclaimed water and extending water resources for each one of them contains different risks and corresponding to that there are different regulations. Moreover, this application and the regulations vary from region to region because of the method of application, water characterization, according to the risk factors that cause the area to which they apply and some other similar reasons.

2.2.1 Urban Reuse

There are many uses of urban reuse water such as irrigation of the recreational field, golf course, and other applications including fire protection and toilet flushing. Some of these methods and the necessary restrictions and guidance to apply such methods are located in Turkey regulations. Examples of such applications are also available in various places in Turkey.

2.2.2 Environmental Reuse

Reclaimed water might be used as water bodies like wetlands, aquatic habitats, and stream flow. Aquifer recharge is another environmental reuse option, but due to the complexity of the subject further studies must be carried out in its application.

2.2.3 Groundwater Recharge

The use of reclaimed water to recharge aquifers practice as a disposal method for treated wastewater effluent rather than a potable water source. Reclaimed water can supply a number of rewards such as recharge of adjacent surface streams, recovery of treated water for subsequent reuse or discharge, seasonal storage of treated water beneath the site with seasonal recovery in agriculture. Implementation of this method can lead to many concerns; therefore it is prohibited in Turkey.

2.2.4 Industrial Reuse

The industrial application of reuse water has grown in a variety of industries ranging from electronics to food processing, not the mention a broader adoption by the power-generation industry. Some of these industries have embraced the use of reclaimed water already for range of various purposes. Some of the use of reclaimed water in industrial applications are usage for facilities, power production, extraction of fossil fuels, cooling tower, process water, steam production boiler feed water, and use to flushing toilets and site irrigation other applications like mineral processing, concentrate making, cleaning, and dust control.

2.2.5 Potable Reuse

The use of reclaimed water to provide potable water has a huge potential for new drinking water sources. However, augmentation of a drinking water source of reuse water has several issues particularly the health risks. Therefore, water reuse as

drinking water is not seen much of demanded because of the amount of water available in Turkey.

2.2.6 Agricultural Reuse

The reuse of treated wastewater, in particular for irrigation, is an increasingly common practice, encouraged by governments and official entities worldwide. Despite all these advantages the reuse of water also brings many risks with them. The first of them and the most important one effects on health and crops, while some of the others; the system allowing the reuse of water are electricity usage , the cost, environmental impact, etc. This study will attempt to take into consideration of these risks as much as possible. Standards have been reducing risk by using limit values for pollutants and to providing guidance about available alternatives. Criteria related to the reuse of water are usually defined according to standards issued or recommended by local authorities or international agencies to avoid the risks. Turkey has guided by local standards based on the international standards. In this study, the detection of water quality required for use as irrigation water will be carried out according to standard Turkey.

The water quality should be sufficient to protect human health when consuming food produced from reclaimed wastewater irrigation. In addition, direct contact with irrigated crops can cause health problems upon humans as well as animals. Therefore necessary precautions to avoid these risks should be taken in these areas and there must be warnings in the location (e.g. Management practices to interrupt the flow of pathogens), and selected to suit local circumstances (including crop selection; water application measures/control; and human exposure control). Components of reclaimed irrigation water can be degraded by microorganisms present in the soil in some cases. Moreover, the reuse water for irrigation purpose comes with other risks in terms of worsening groundwater quality, soil characteristics, and plant health issued.

Irrigation water causes some problems such as high level of nitrogen and phosphate, which necessary nutrient of the plant development but this nutrient easily can enter the groundwater and adversely affects groundwater quality. In extreme cases the nutrient of the water can lead the eutrophication. Other pollution inside the reuse water also must be considered such as heavy metals, growth inhibitors can lead health risk to human and negative effect on plant growth as well.

2.3 Reclamation Technologies

Reclaimed water quality and treatment requirements vary based on the final use of the reclaimed water and exposure potential as well as the technology used to capture this quality. One of the most critical steps in any reuse program is to protect the public health, especially that of workers and consumers. To this end, it is most important to neutralize or eliminate any infectious agents or pathogenic organisms that may be present in the wastewater. For some reuse applications, such as irrigation of non-food crop plants, secondary treatment may be acceptable. For other applications, further disinfection, by such methods as chlorination or UV, may be necessary. There are many different treatment technologies and new ones are being added every day. Membrane technology is a fairly common use between them.

2.3.1 Membrane Technologies

Membranes are a separation process using membranes with different pore size and depending on the pore sizes to remove high molecular-weight substances (colloidal materials, and organic and inorganic polymer molecules) or low molecular-weight organics and ions (sodium, calcium, magnesium chloride, and sulfate) with the help of a pressure.

There are many types of membrane modules used and they can be classified as according to the pore size or configurations.

2.3.1.1 Membrane Types

Membrane technology main goal is selective penetrations which are easily used for water treatment thank to the various thickness options. The thickness determines the type of pollution to separate and membranes name of their thickness size. The separations via membrane technology also need pressure and consequently electricity to obtain this pressure. Membranes treatment has a two different application to attach the process: homogeneous or heterogeneous. There are two types of membrane material which are synthetic membranes and biological membranes. There are two types of operation modes for membranes can also be varied as dead end filtration and cross flow filtration inside a module of the membrane.

Membranes can also be categorized via thickness level as Reverse Osmosis (RO), Nanofiltration (NF), Ultrafiltration (UF) and Microfiltration (MF) according to pore size. Figure 2.2 shows the categorization of membranes based on the pore size and as shown in the figure, membrane type should be determined considering the contaminants that will be removed.

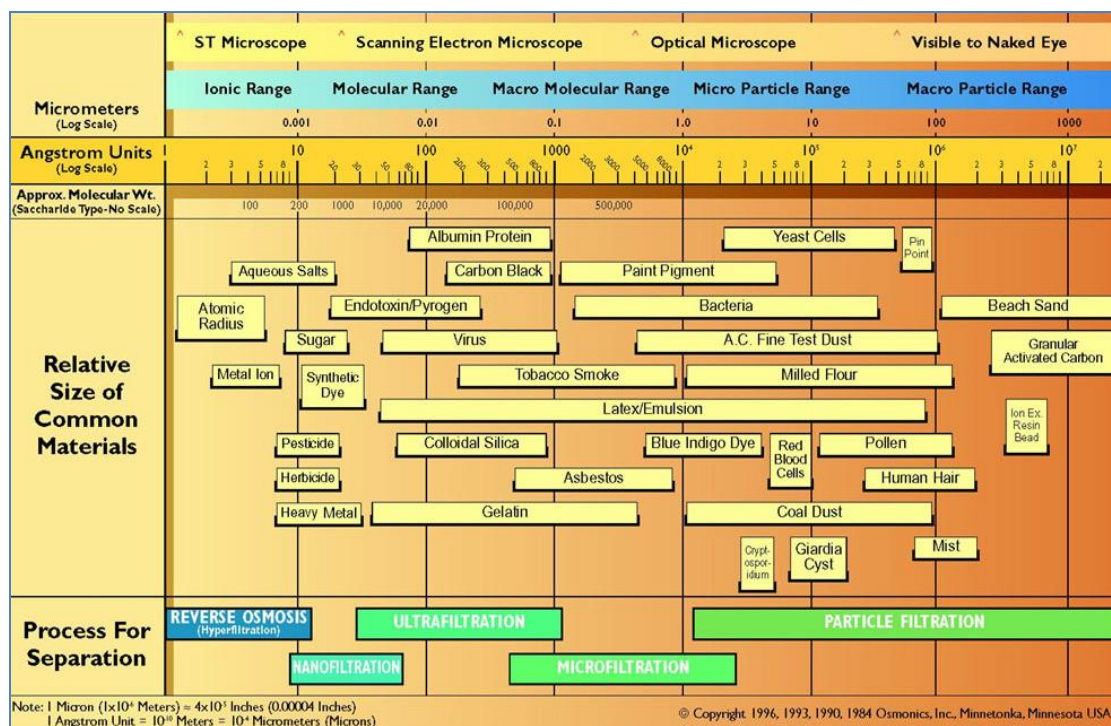


Figure 2.2 The filtration spectrum (Seine, 1996)

Microfiltration is used to remove residual suspended solids (SS), to remove bacteria in order to condition the water for effective disinfection and as a pre-treatment step for reverse osmosis but unlike UF cannot remove viruses. Hence, depending on wastewater use and the receiving environment additional treatment might be necessary to apply. Microfiltration can also be used as pre-treatment before RO to avoid blockage or combined with MBR.

Ultrafiltration may use for many of the same purposes as microfiltration which being used as a dissolved compound remover for high molecular weight, such as proteins and carbohydrates and bacteria. Over and above, they are able to remove viruses and some endotoxins.

2.3.2 Disinfection

The primary goal of water treatment is to ensure that the water is safe to use and one of the most important goals to insure; water does not contain any disease-causing microorganisms. The process of removing harmful bacteria and impurities is called the disinfection. There are many methods of disinfection such as boiling method, excess lime treatment, iodine and bromine treatment, silver treatment and some oxidation treatment options like ozone treatment, potassium permanganate treatment in addition to that ultraviolet ray treatment.

Disinfection is achieved by UV rays while wastewater passes through the bulbs. For generating the rays, the mercury is enclosed in one or more quartz bulbs and electric current is then passed through it. The UV treatment process is a rapid physical process that causes a molecular rearrangement of the genetic material, known as DNA of the microorganism which DNA is the main constituent of all chromosomes of all organisms, known as deoxyribonucleic acid, and it can replicate itself. Once microorganisms are exposed to UV light they are becoming inactive and can no longer replicate themselves anymore, meaning they can no longer cause infection or produce colonies. UV light can effectively disinfect wastewater in an environmentally friendly way because of no chemical usage and forms no by-

products like chlorine, which produces dangerous carcinogens may impact the environment.

2.4 The LCA Concept

Life cycle analysis (LCA) is a tool to systematically estimate a product or process complete phrases, from raw materials to final disposal while considering environmental impacts and cost calculation in every step.

LCA concept comes from early seventies, the development and application of LCA have been emerged some of international bodies such as:

- SETAC (the Society of Environmental Toxicology and Chemistry)
- ISO (the International Organization for Standardization)
- UNEP (the United Nations Environmental Program)

LCA standards were developed by the International Organization for Standardization (ISO) specifically ISO 14040 and ISO 14044. Life cycle assessment firstly described in ISO 14040 and ISO 14044.

The 14040 series has produced some standardization about Environmental management - Life cycle assessment so far by ISO:

- ISO 14040: A standard on principles and framework.
- ISO 14041: A standard on goal and scope definition and inventory analysis.
- ISO 14042: A standard on life cycle impact assessment.
- ISO 14043: A standard on life cycle interpretation.
- TR 14049: A technical report presenting examples for ISO 14041 on the life cycle inventory phase.

LCA is used to investigate of the process for resource usage (water, raw material, energy, etc.), pollutants (emissions, wastewater, waste, etc.) from result of the process. These resources usage and pollution effect on the environment has divided into categories due to their impacts; such as global warming potential, acidification

potential, eutrophication potential, ozone layer depletion potential, abiotic depletion elements, freshwater aquatic ecotoxicity potential, human toxicity potential, photochemical ozone creation potential, and terrestrial ecotoxicity potential.

LCA is composed of a number of structural sections as illustrated in Figure 2.3.

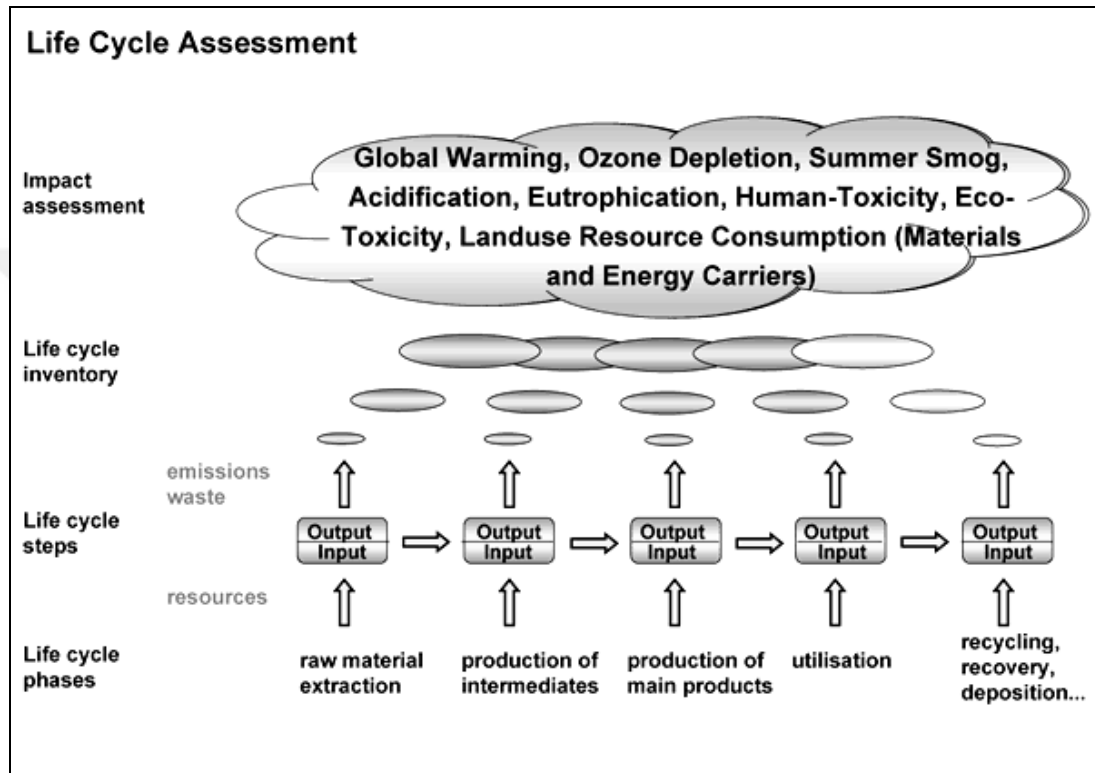


Figure 2.3 Generalised overview of life cycle analysis process, (Duinen and Deisl, 2011)

Life Cycle Assessments are performed via identified four steps which are prepared by ISO standard, as shown in Figure 2.4 as an LCA Framework.

1. Goal and Scope
2. Inventory Analysis
3. Impact Assessment
4. Interpretation

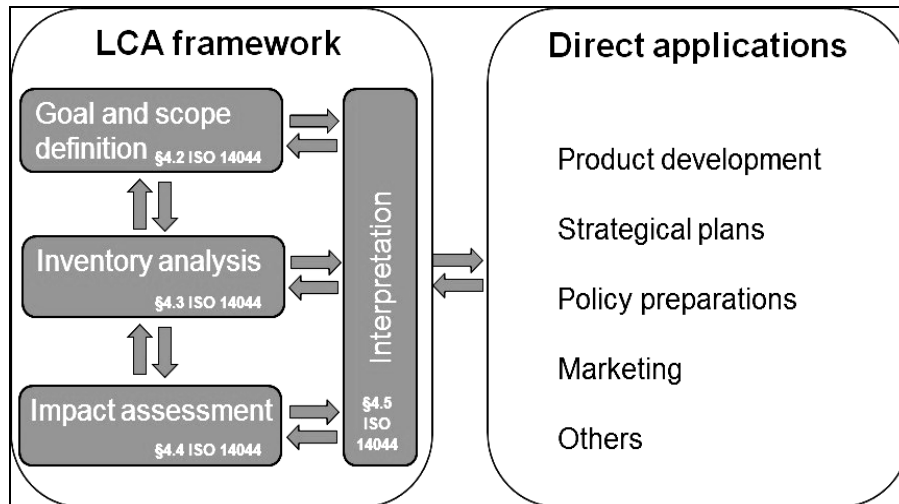


Figure 2.4 Steps of a life cycle assessment according to ISO 14044,(Finkbeiner- Inaba et al., 2006)

2.4.1 Goal and Scope Definition

A general introduction about the LCA study should be performed in the goal and scope section of examining. Following information may be mentioned in this section: The intend of application, the objectives for carrying out the study, the intended audience whom the results of the study are intended to be communicated, whether the results are intended to be used in comparative assertions intended to be disclosed to the public.

Moreover the consequential topics can be addressed in this section too: The reference flow, the product system(s) under study, and the main characteristics of the intended LCA study. But the essential information in this section is system boundaries and functional unit definitions.

System boundaries define the borders of the system and processes, process flow and the impact to be considering extending of LCA investigation. Therefore the inputs and outputs of the process should be determined through this step.

2.4.1.1 Goal

The definition of the goal is basically is the purpose of the study, therefore it effects all other choices we've made throughout the study. The importance of the goal came from this basic fact.

LCA can be used for different purposes which are given below:

- To compare more than one process
- To identify possible improvement and further development
- To ecolabelling studies

2.4.1.2 Scope

The pattern of the study is defined by scope phase of LCA. In other words, it sets a boundary for the study and effects both the causes and result of the study. But most importantly, it must match with the goal phase of the study. The following critical steps for LCA is considered in scope definition such as, functional unit, system boundaries, types of impact , data requirement and the type and format of the report required for the study. Scope must be matched length to achieve the goal.

2.4.1.2.1 Functional Unit. Investigation of a system via LCA requires a mutual unit system which identified as the functional and it is very useful when it comes to, comparison of two or more processes or improvement of the one product (system). Data collection in the inventory phase and also the goal and scope of the study depend on the functional unit. The mathematical calculation foundations which are called normalization build upon the functional unit.

2.4.1.2.2 System Boundary. The system boundary determines the processes included or exulted to LCA investigations. The system boundary is depending of the goal and scope definition and heavily effect the result of the study. The system boundary included detail decision making information regarding to processes.

System boundaries can be expanded as natural resource use such as the receipt of raw materials to effect on the end of the processes. System boundary created by the inputs - outputs and product flows. The calculation of LCA carried out to identify the environmental impact of selected system boundary.

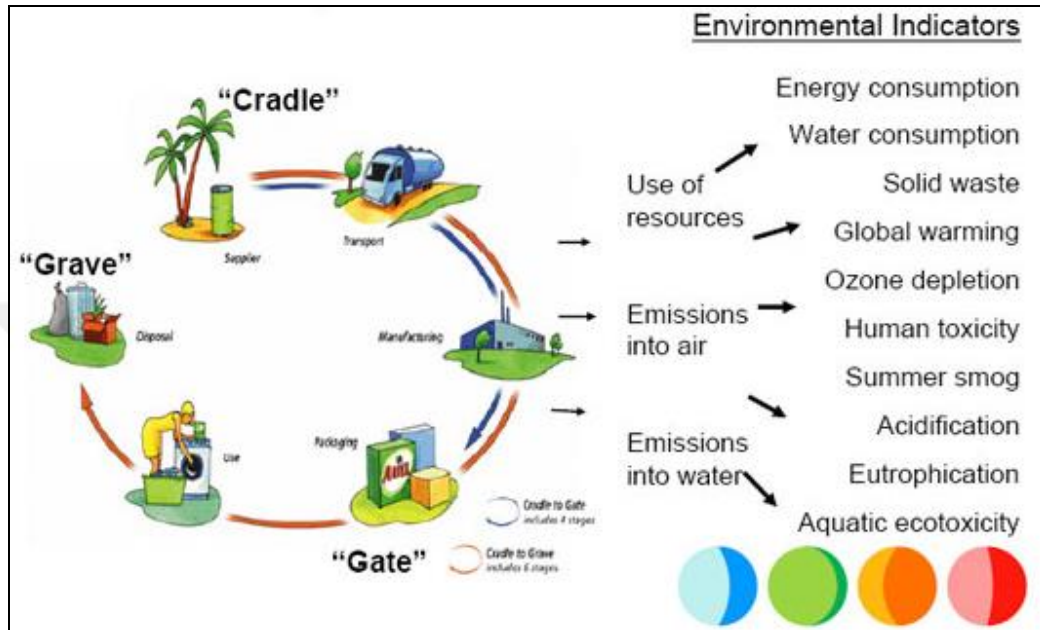


Figure 2.5 System boundaries of a life cycle assessment (Sauers, 2008).

There are four main system boundaries options of a Life Cycle Assessment used: “Cradle to Grave”, “Gate to Gate”, “Cradle to Gate”, and “Gate to Grave”. As seen in the Figure 2.6; “Cradle to Grave” is the most extensive borders; “Gate to Gate” approach on the other hand is the narrowest limits. It varies depending on the objective of the study to choose the approach type.

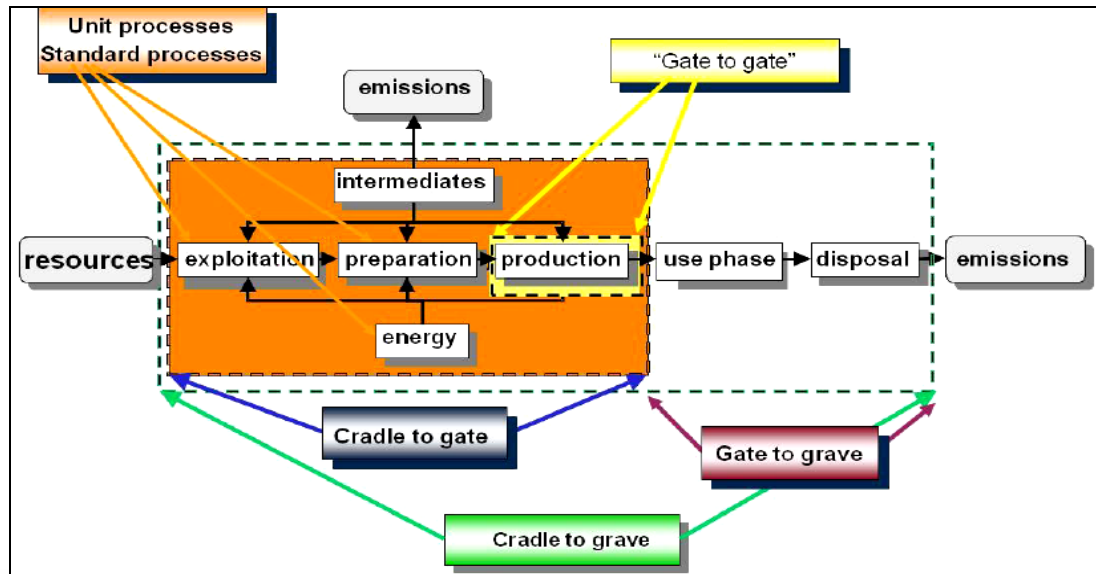


Figure 2.6 Details the selection of a system boundary for LCA studies according to ISO 14044, (Duinen-Deisl, 2011)

2.4.2 Inventory Analysis (LCI)

Inventory Analysis of the LCA phase interests lines with inputs and outputs of the system and all the data relating to the system. Inputs can be defined as what system need to work, outputs on the other hand is the leftovers or unwanted pollution which occurs during the system working. For example: energy, raw materials can be identified as inputs. Emissions, products, energy can be example for outputs. Data gathering and data selection are also inside the scope of life cycle inventory analysis, which directly link to the result of environmental effect calculation. Data may be collected from direct sources like factories, laboratory or as a secondary source as literature. Data may be collected from direct sources like factories, laboratory or as a secondary source as literature.

To put it simply, the LCI manifests the numerical values of the pollutants affecting the environment. The classification is the conversion of Inventory Analysis (LCI) to The Life Cycle Impact Assessment (LCIA).

2.4.3 Life Cycle Impact Assessment (LCIA)

LCIA converts numerical data to environmental effect equivalent via some determined factor multiplication. It's a transformation tool to convert mathematical data to environmentally significant pollution type and unit and prepares a calculation to the next phase which called characterization. The more detailed explanation between LCI, LCIA, classification and characterization are summarized in Figure 2.7. As seen in the chart LCI reveals the value of the amount as a unit; then classification divides into groups according to the environmental impact of this value; afterwards characterization is multiplies this amount of value by a factor which is depending on how much affect to that category. These factors vary depending on the evaluation method. Finally, the ultimate effect on environment achieves as LCIA. Table 2.1 gives information about the impact categories used.

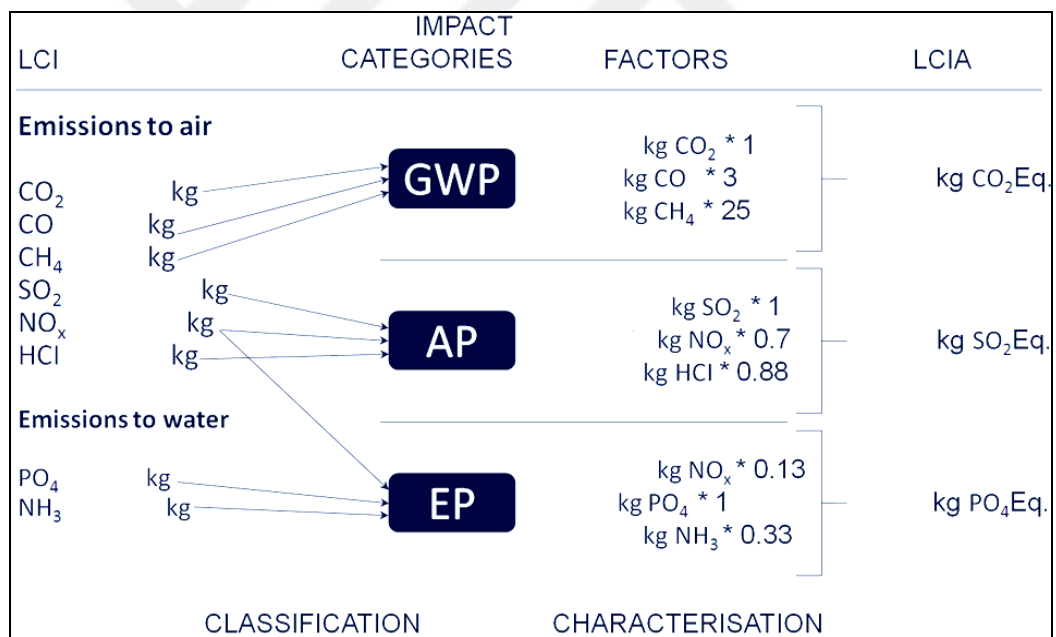


Figure 2.7 Classification and characterization (Duinen-Deisl, 2011)

To simply summarize; Life Cycle Impact Assessment (LCIA) is effect type of polluting on the environment.

2.4.3.1 Characterization

The outcome of the LCIA phase is tuned into more significant readable result by the characterization phase. Pollution type and unit turned into environmental impact categories which explain better the significant impact on the environment. Characterization factors are used for conversions. These factors are determined by different scientific groups, the most widely used ones are TRACI and CML. Environmental impact assessment methodologies are summarized in Table 2.1.

Table 2.1 Environmental impact assessment methodologies (Hauschild, 2010)

Method	Developer	MP	EP	Description
CML 2002	CML (NL)	x		One of the first methods and frequently used; separate normalisation factors for each indicator, in total 19 impact categories.
Eco-indicator 99	Pré (NL)		x	Three perspectives: Hierarchist, Individualist and Egalitarian. One fully integrated approach which covers all impact categories resulting in damage to human health, ecosystems and resources.
EDIP97 and EDIP2003	DTU (DK)	x		Classic emission-related impact categories as well as resources and working environment. Normalisation and weighting is based on political environmental targets.
EPS2000	IVL (SE)		x	Expression in monetary units derived on the Willingness To Pay (WTP) principle.
Impact 2002+	EPFL (CH)	x	x	14 midpoint categories are linked to four damage categories (human health, ecosystem quality, climate change, resources). Normalisation either at midpoint or at damage level.
LIME	AIST (JP)	x	x	Expression in monetary units. One single index based on the midpoint to the endpoint. Weighting is based on environmental conditions of Japan.
LUCAS	CIRAIG (CAN)	x		Related to Canadian context based on TRACI and Impact 2002+.
ReCiPe	RUN + Pré + CML + RIVM (NL)	x	x	Follow up of Eco-indicator 99 and CML 2002. It harmonises midpoint and endpoint approaches.
Swiss Ecoscarcity 07	E2 + ESU-services (CH)	x	x	Weighting is based on public policy targets and objectives. Originally developed for Swiss conditions, but already adapted to other European countries.
TRACI	US EPA (USA)	x		Related to conditions in the USA and in line with the EPA policy.
MEEuP	VhK (NL)	x		Evaluation of various energy-using products (EuP) and their extent of fulfilling certain criteria for implementing measures under the Ecodesign of EuP Directive 2005/32/EC.

The impact categories and the significant pollution to calculate them can be seen at Table 2.2.

Table 2.2 Commonly used life cycle impact categories. Design for Environment as a Tool for the Development of a Sustainable Supply Chain (Bevilacqua-Ciarapica et al., 2012)

Impact Category	Scale	Examples of LCI Data (i.e. classification)	Common Possible Characterization	Description of Characterization Factor
Global Warming	Global	Carbon Dioxide (CO ₂) Nitrogen Dioxide (NO ₂) Methene (CH ₄) Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Methyl Bromide (CH ₃ Br)	Global Warming Potential	Converts LCI data to carbon dioxide (CO ₂) equivalents Note: global warming potentials can be 50,100, or 500 year potentials.
Stratospheric Ozone Depletion	Global	Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Halons Methyl Bromide (CH ₃ Br)	Ozone Depleting Potential	Converts LCI data to trichlorofluoromEthene (CFC-11) equivalents.
Acidification	Regional Local	Sulfur Oxides (SO _x) Nitrogen Oxides (NO _x) Hydrochloric Acid (HCL) Hydroflouric Acid (HF) Ammonia (NH ₄)	Acidification Potential	Converts LCI data to hydrogen (H ⁺) ion equivalents.
Eutrophication	Local	Phosphate (PO ₄) Nitrogen Oxide (NO) Nitrogen Dioxide (NO ₂) NitratesAmmonia (NH ₄)	Eutrophication Potential	Converts LCI data to phosphate (PO ₄) equivalents.
Photochemical Smog	Local	Non-mEthene hydrocarbon (NMHC)	Photochemical Oxidant Creation Potential	Converts LCI data to Ethene (C ₂ H ₆) equivalents.
Terrestrial Toxicity	Local	Toxic chemicals with a reported lethal concentration to rodents	LC50	Converts LC50 data to equivalents; uses multi-media modeling, exposure
Aquatic Toxicity	Local	Toxic chemicals with a reported lethal concentration to fish	LC50	Converts LC50 data to equivalents; uses multi-media modeling, exposure
Human Health	Global Regional Local	Total releases to air, water, and soil	LC50	Converts LC50 data to equivalents; uses multi-media modeling, exposure pathways.
Resource Depletion	Global Regional Local	Quantity of minerals used Quantity of fossil fuels used	Resource Depletion Potential	Converts LCI data to a ratio of quantity of resource used versus quantity of resource left in reserve.
Land Use	Global Regional Local	Quantity disposed of in a landfill or other land modifications	Land Availability	Converts mass of solid waste into volume using an estimated density.
Water Use	Regional Local	Water used or consumed	Water Shortage Potential	Converts LCI data to a ratio of quantity of water used versus quantity of resource left in reserve.

2.4.4 Interpretation

Interpretation phase of life cycle assessment is used for evaluation, identification, qualification and basically checking through the all LCA process phrases.

Identification and evaluation are the two main steps of the interpretation phase of LCA. Identification determines which data elements the most important effects on the results for the phases of the LCA. Evaluation, on the other hand, checks for completeness like any incomplete or missing information. Also check for phrases to satisfying of the goal and scope definition.

2.4.5 LCA Databases and Software

An LCA can be applied through manual calculations using a math program or Microsoft Excel or by LCA software that included programs to become more specific in this regard. The most commonly used software and databases are listed below:

- Boustead Model 5.0
- ECO-it
- Gabi Model 4
- GEMIS Model 4.5
- Green-E
- IDEMAT
- REGIS Model 2.3
- SimaPro Model 7
- TEAM Model 4
- Umberto Model 4.1

2.4.5 LCC

Life Cycle Assessment process can be used for cost calculation which called Life Cycle Costing (LCC) approach. LCC can be calculated via mathematical methodology or software as well. Cost calculation might use narrowed or expended depending on the needed cost information. There is a standard for LCC in ISO Standardization numbered as ISO 15686-5. There are some LCC calculation tools such as ACEIT, Ampsol, Bid-Builder, BLCC 5.3, Kostenreferentiemodel, LCCID, LCProfit , LCCWare 3, PARAP, RealCost 2.1, Relex LCC, GaBi.



CHAPTER THREE

MATERIALS AND METHODS

3.1 Scale of LCA System

In this study, environmental impacts of reuse wastewater which could be used for purposes of agricultural irrigation, treatment alternatives were investigated through LCA and LCC approach, with the help of GaBi software version 6.0. Three different scenarios were determined in this investigation (Case 1 - Case 2 – Case 3).

3.2 Goal and Scope Definition

3.2.1 Goal

The main purpose for this investigation was determined the impacts of reuse applications to the environment. Because, membrane technologies frequently considered as expensive, another important point for deciding processes, was to compare the cost between the cost of purchasing and the cost of maintenance. Different energy source impact on the environment was also investigated as a part of the goal. Some variations were used throughout the investigation. Therefore, this investigation could be used for guidance in many matters.

The result might have been used for decision making among different reuse options by environmental engineers or other decision-makers. Three different reuse alternative scenarios were chosen for this purpose. They had been chosen based on commonly used and their effectiveness. To improvement possibilities in further development of existing reuse alternative or in innovation and design of new alternatives and the most importantly investigate to the environmental impact of environmental friendly solution was concerned goal of this investigation. The study could have given the inside information about detailed environmental impacts of wastewater treatment like Global Warming Potential, Eutrophication Potential, and

etc. Different type of impact methodology result which had been used in the study could be given an idea of methodology selection. Choosing the energy source may have been underestimated when designing a system, this study also could be illuminated in that area as an aspect of environmental impact.

3.2.2 Scope

Utilizing a similar study, assumptions were made to create scope of the study. Following steps were performed to achieve scope definition (Figure 3.1):

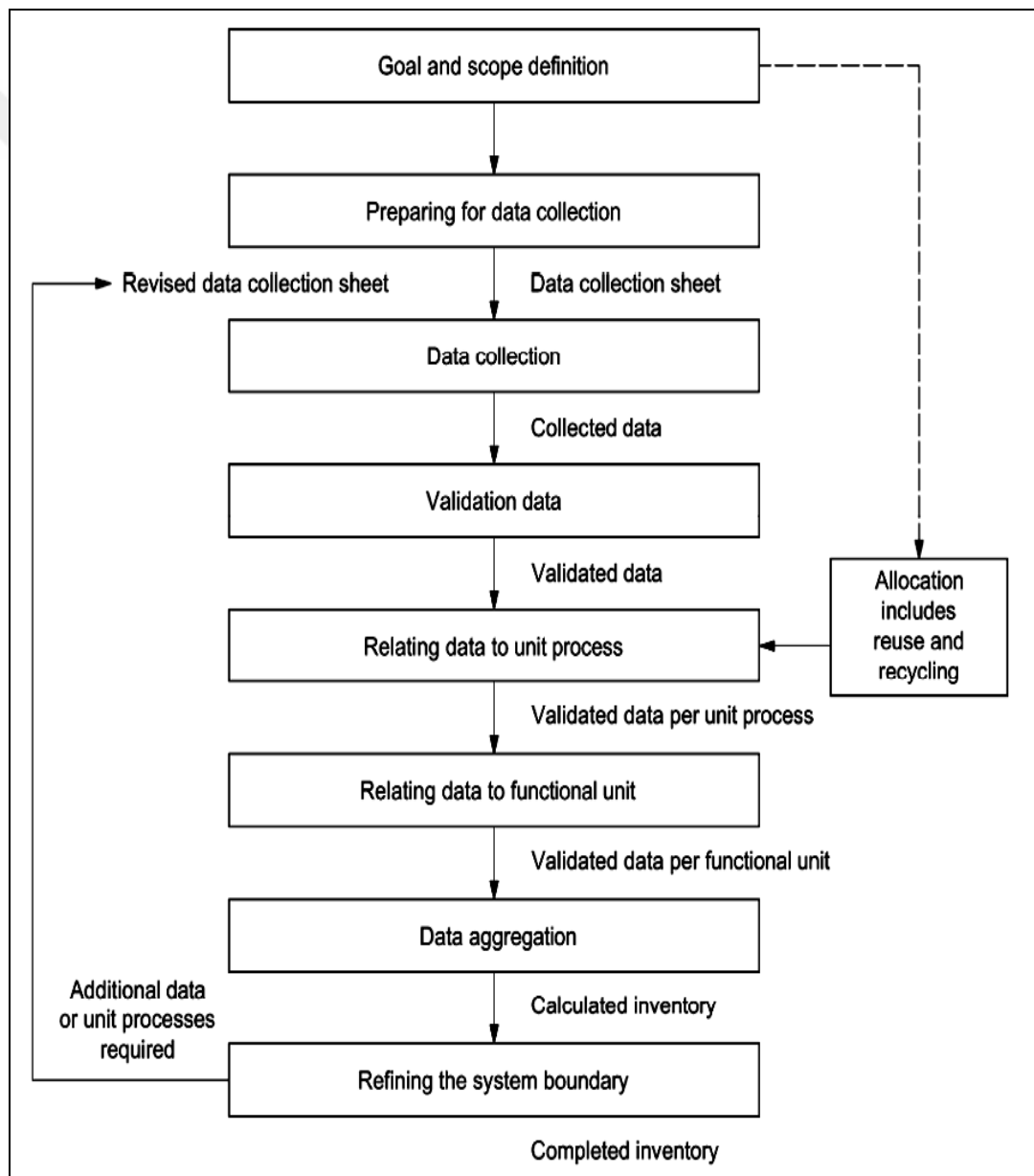


Figure 3.1 Classification and characterization; (Duinen-Deisl, 2011)

3.2.2.1 Function of the System

The single functional unit had been selected to compare alternatives more accurately.

3.2.2.2 Functional Unit

The functional unit was chosen to be delivery of 1 m³ of recycled water to be used for irrigation of sensitive crops such as bean, almond, apricot, plum, and grape which is a very common functional unit for water. Functional unit had been a critical reference to calculation of input and output data normalization due to that reason the functional unit was chosen as the smallest unit. Thus, if it's desired to observe the effect of any amount of wastewater, it could determine by LCIA value multiplying with the flowrate of the wastewater.

3.2.2.3 System Boundaries

System boundaries were considered as effluent from WWTP had been investigated since then come to the Reuse Treatment Facility (RTF). Effluent wastewater transportation to the treatment plant was ignored since this is common for all treatment options. Reuse water from the RTF used in irrigation applications and their effects was ignored for the same reason. Only water effluent from WWTP entering the RTF treatment processes was taken into account as the system boundaries to be used for irrigation degree of sensitive crops.

Two different energy sources were chosen to run the system, especially keep operating of MF, UF, UV, filtration (cartage filter) and backwashed of MF and UF. These two energy sources were chosen as electric grid mix for Turkey and natural gas to electricity for Turkey. GaBi database calculates all the process of providing energy as well, such as emission to air, etc. Electric grid mix process selected for Turkey from GaBi database. GaBi also considers electricity source changes for each

country. Some countries use coal or some type of coal to provide electricity. Therefore, this study result applies for Turkey. This different energy source selection identified as Scenario 1 and Scenario 2 in the scope of this study. Backwashing of the membrane system needs several times more pressure than the operation phase of the system since backwashing occurs opposite site of the normal water flow. Moreover UF has a narrower pore size than MF therefore needs more pressure which obtains from electricity. The system boundary of the each case and some of the system components are given in Figure 3.2. The treatment units used in these cases were chosen considering effluent quality requirements for sensitive crop irrigations in Water Pollution Control Regulations Notification for Technical Principles Table E7.1 (Official Newspaper, 2010).

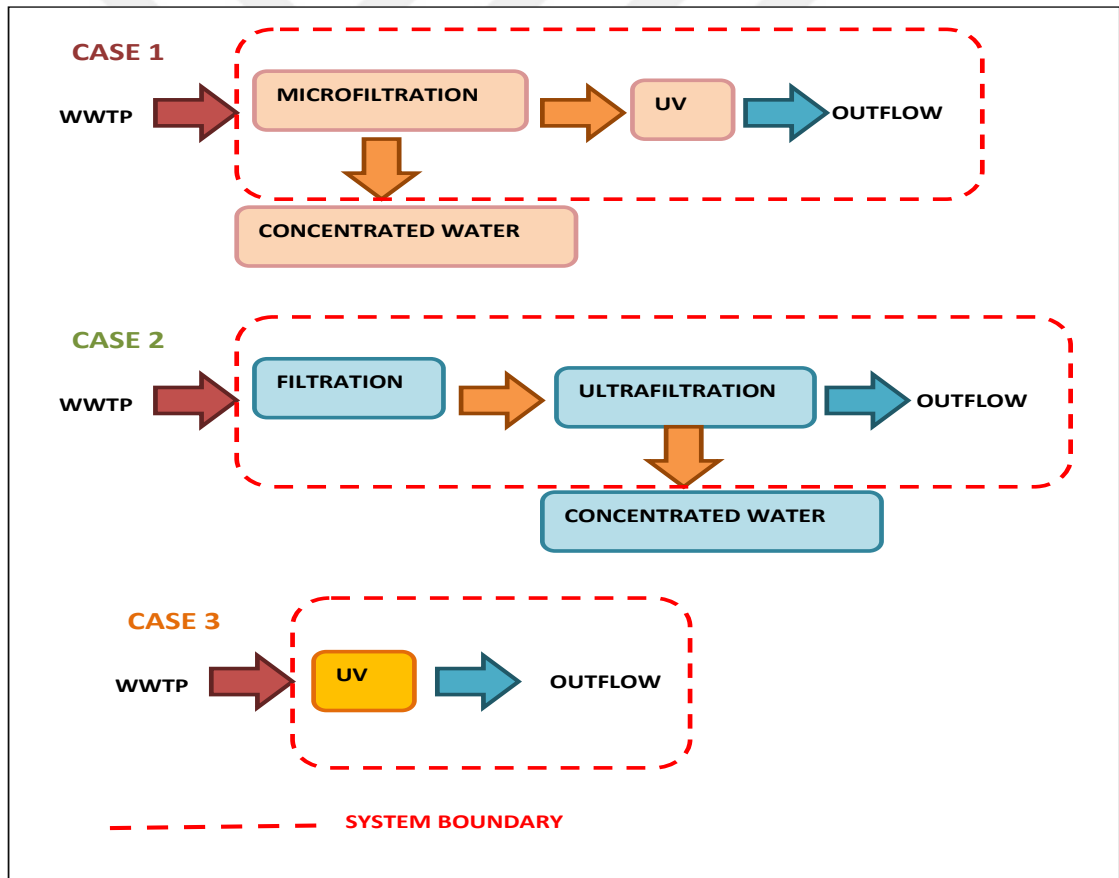


Figure 3.2 The system boundary of the cases

“Gate to Gate” approach was selected which included the materials and processes from the further treatment phase only and nothing more due to the scope of the study purpose.

Two different scenarios for each case were chosen considering the energy source:

- Scenario 1: Energy source was chosen as Electric Grid Mix for Turkey from Gabi Database.
- Scenario 2: Energy source was chosen as Energy from Natural Gas for Turkey from Gabi Database.

Since Scenario 1 was considered as more impact than the Scenario 2 to the environment, LCC calculation was carried out for an electric grid mix in Scenario 1.

3.3 Inventory Analysis (LCI)

3.3.1 Allocation Procedures

The allocation to different products was done according to mass balance. For each of the scenarios, same input mass was selected. Energy input was modified according to each processes need. The average effluent quality of several treatment plant effluents in Turkey was accepted as input water quality (Table 3.1).

Table 3.1 Input water (WWTP effluent) quality parameters used for the LCA modeling

Water quality parameters	Values
Chemical Oxygen Demand (COD)	85 g/m ³
Biological Oxygen Demand (BOD)	15 g/m ³
Suspended Solid (SS)	15 g/m ³
Total Nitrogen (TN)	5 g/m ³
Total Phosphorus (TP)	0,5 g/m ³

Many variables had been considered in the cost calculations. Membrane presumed as backwashed periodically. The chemical type and the amount of chemical material,

water, energy usage, and attendance personnel (one personal for both maintenance and operating duty) of this procedure were considered in calculations (Qiang and Robinson, 2013).

Membrane also needs the pressure to operate this pressure maintains via electrical power (Durkam, 2000). Each system pressure need is different from the other and it affects their electric consumption (Dumez, 1996). Membrane technology (UF and MF) also has to replace completely due to deterioration with time and accumulated pollution (Tnagsbul- Parameshwaran et al., 2006). Initial, operation, maintenance, and personal costs were also added in LCC calculation. Maintenance cost considered as backwashed (chemical amount and price included) and membrane changing cost for UF and MF. Backwashing process implemented via chemicals and maintenance or operation of the system carried out via personal and personnel salary also included in LCC calculations. Replacement of the membrane and the operation period was included in cost calculations. Cartage filter had been considered with similar needs.

UV treatment has a downside as broken or damaged lamp issue which leads adverse effects in the treatment of wastewater, therefore it was assumed that all lamps was replaced at least one time within one year period. Hence investment cost of UV system is high depending on the purchasing of new lamps and this is directly effects the LCC calculation.

3.3.2 Data Quality Requirements

Considerable cutoff criteria were used in LCA practice which inputs were included in the environmental assessment, such as mass, energy and cost. These inputs were decided as conventional treated wastewater quality criteria. Mass was selected as an average level polluted outflow of Wastewater Treatment Plant. As an energy source, natural gas of Turkey was selected from Gabi Database. Determination of cost was designed with the help of articles and previous studies.

3.4 Life Cycle Impact Assessment (LCIA)

As an IPCC factor, CML (Centre for Environmental Studies) by University of Leiden had been chosen. The methodology of Life Cycle Impact Assessment was selected as CML 2001- LCIA-CML 2001 due to commonly usage of similar studies.

3.5 Interpretation

Most environmental impact categories had chosen based on their significance and other LCA studies investigations:

- 1) Global Warming Potential [kg CO₂-Equiv.]
- 2) Acidification Potential [kg SO₂-Equiv.]
- 3) Eutrophication Potential [kg Phosphate-Equiv.]
- 4) Ozone Layer Depletion Potential [kg R11-Equiv.]
- 5) Abiotic Depletion elements [kg Sb-Equiv.]
- 6) Freshwater Aquatic Ecotoxicity Pot. [kg DCB-Equiv.]
- 7) Human Toxicity Potential [kg DCB-Equiv.]
- 8) Photochemical Ozone Creation Potential [kg Ethene-Equiv.]
- 9) Terrestrial Ecotoxicity Potential [kg DCB-Equiv.]

These categories were chosen to compare the environmental impacts of all generated scenarios (Case 1-2-3 and Scenario 1-2).

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Results for Scenario 1

In Scenario1, it was accepted that electric grid-mix are used as an energy sources. In this scenario, three different cases were into consideration. The results are given in the following subsections.

4.1.1 Case 1

In Case 1, it was assumed that conventional domestic WWTP effluent treated with microfiltration and UV before reuse application. Energy source was chosen as electric grid-mix. Processes and flows for each case and scenario were generated. Every type of material transfer performed via flows and heavily depending on the law of conservation of mass or principle. The processes inside the system boundaries can be seen in Figure 4.1.

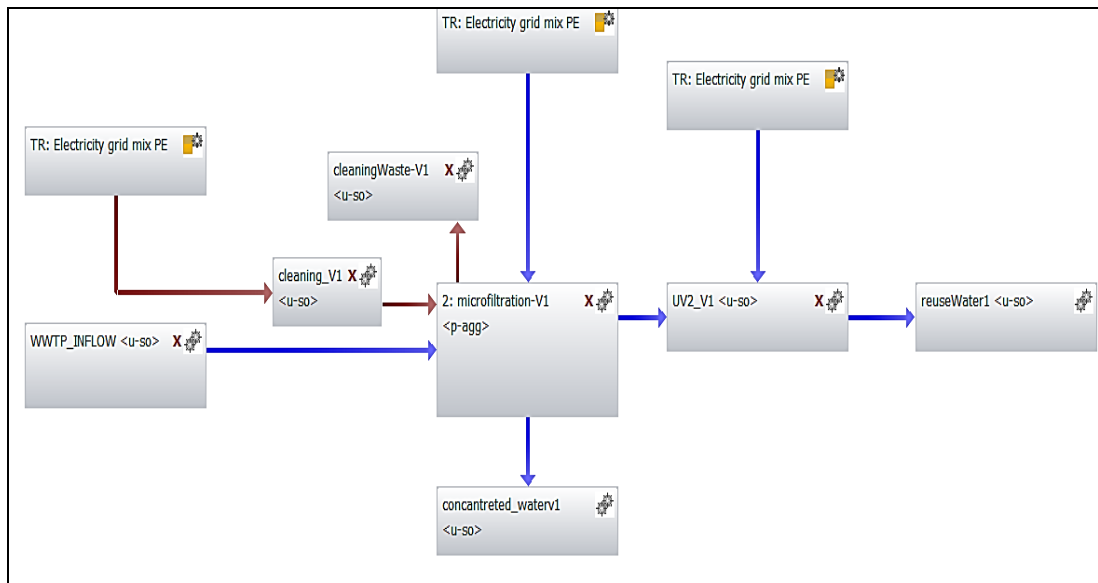


Figure 4.1 Plan for Case 1 – Scenario 1

The results for Case 1 – Scenario 1 were given Figure 4.2 – Figure 4.13. GaBi calculates the effect of every process on environment separately and shows the result on the graphics for the chosen impact categories.

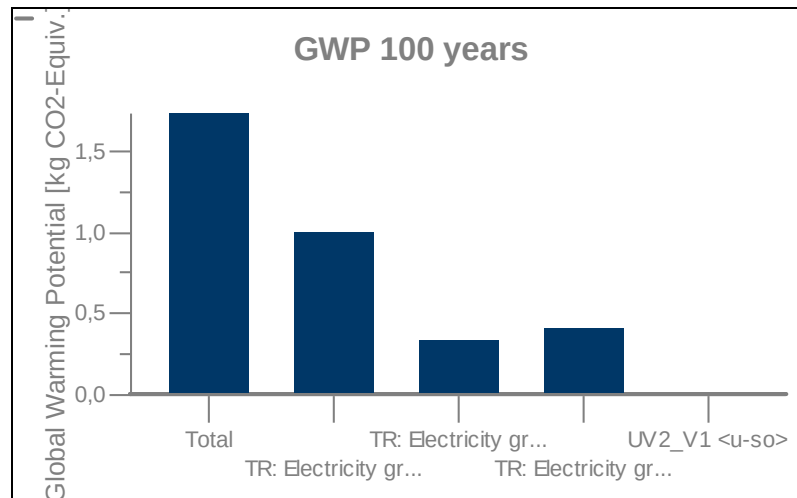


Figure 4.2 Global Warming Potential

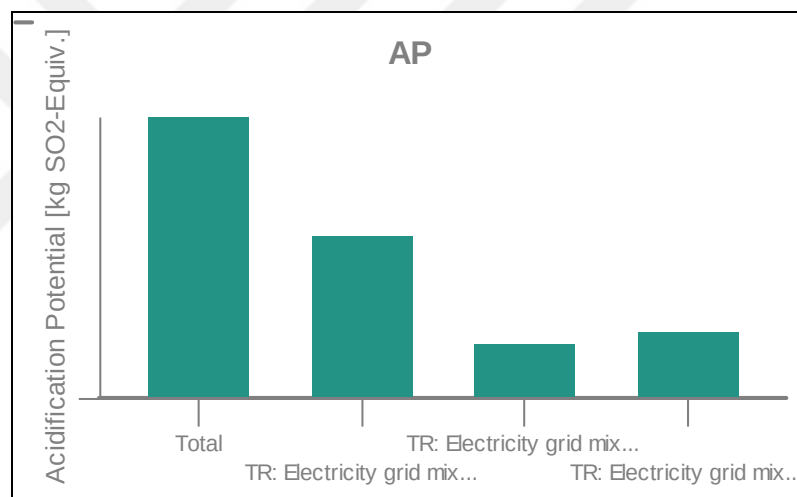


Figure 4.3 Acidification Potential

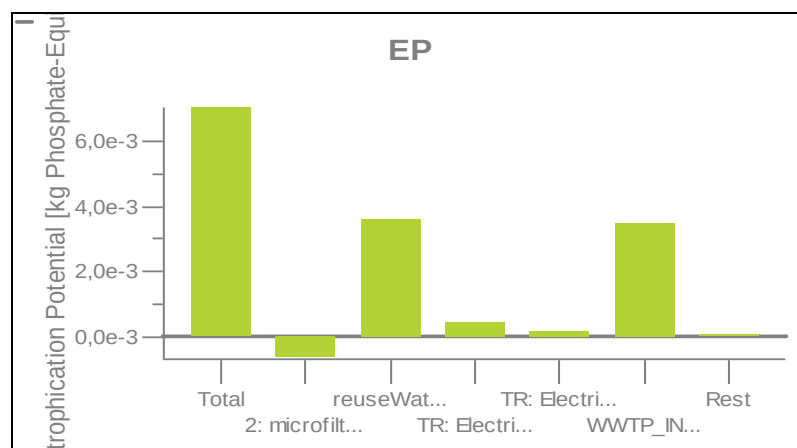


Figure 4.4 Eutrophication Potential

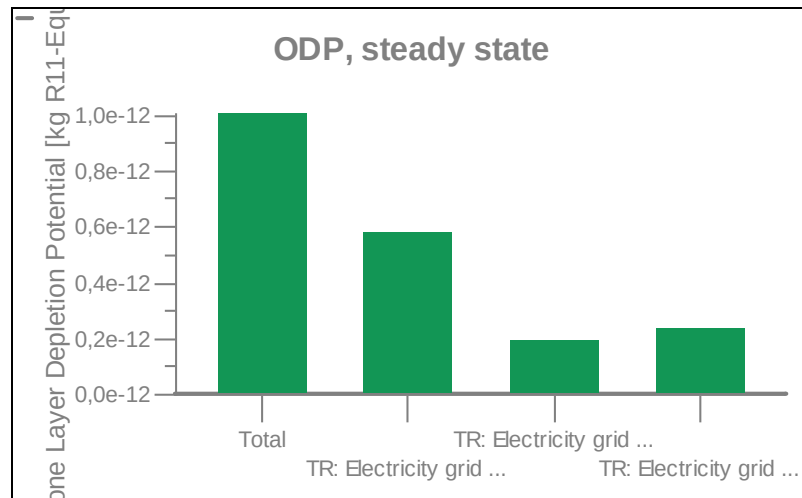


Figure 4.5 Ozone layer depletion potential

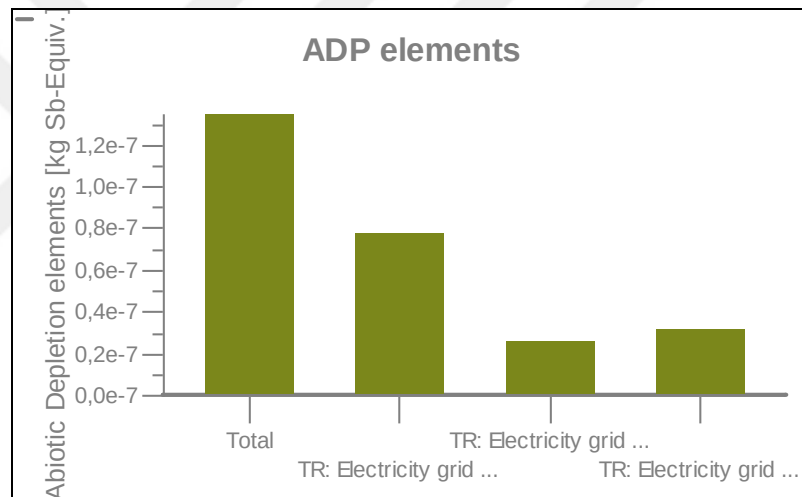


Figure 4.6 Abiotic depletion potential elements

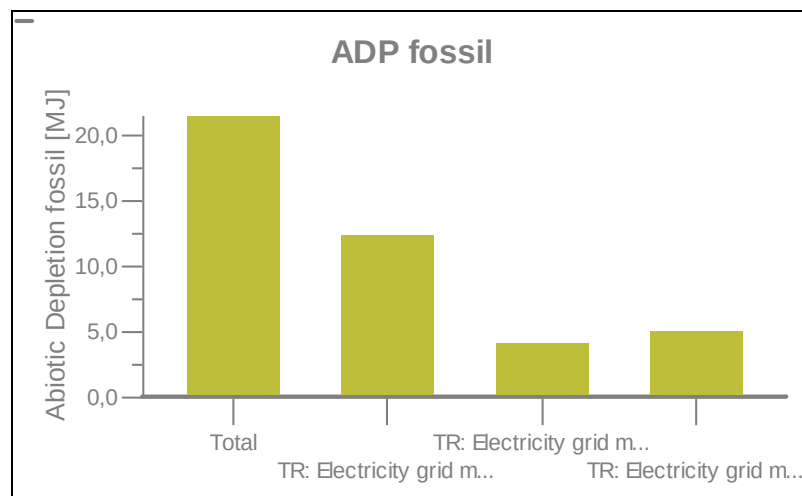


Figure 4.7 Abiotic depletion potential-fossil

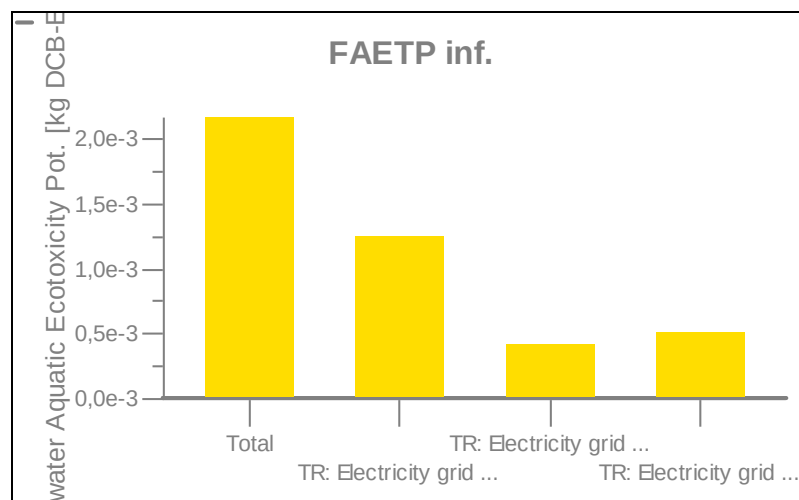


Figure 4.8 Freshwater aquatic ecotoxicity potential

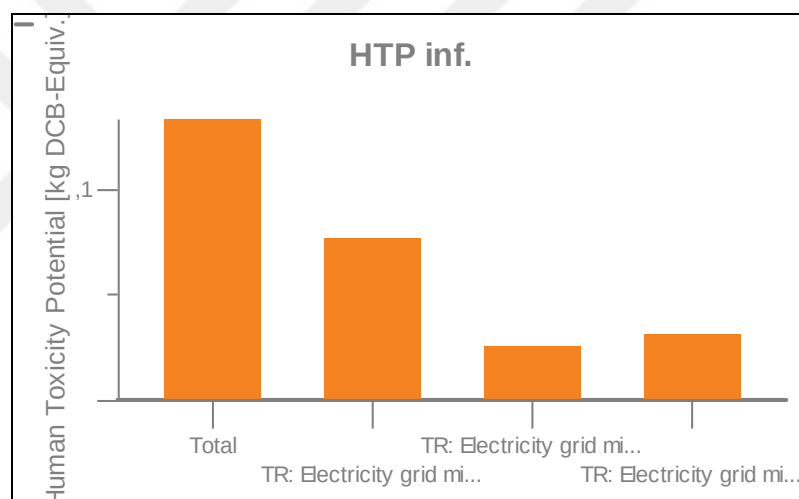


Figure 4.9 Human toxicity potential

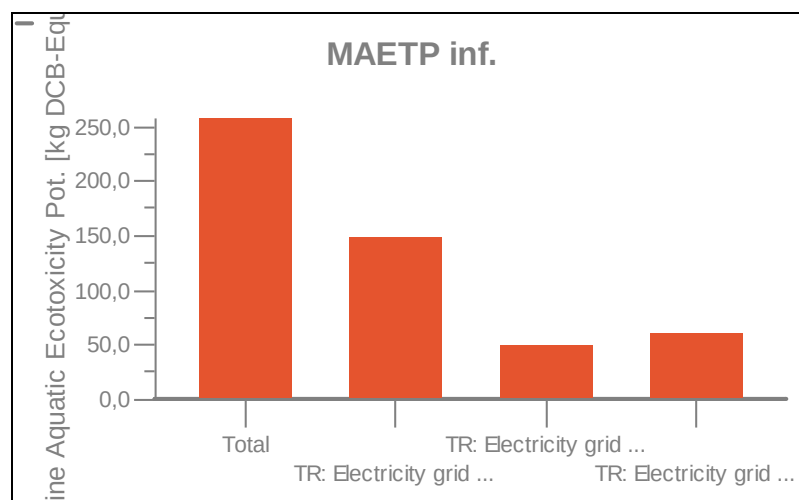


Figure 4.10 Marine aquatic potential

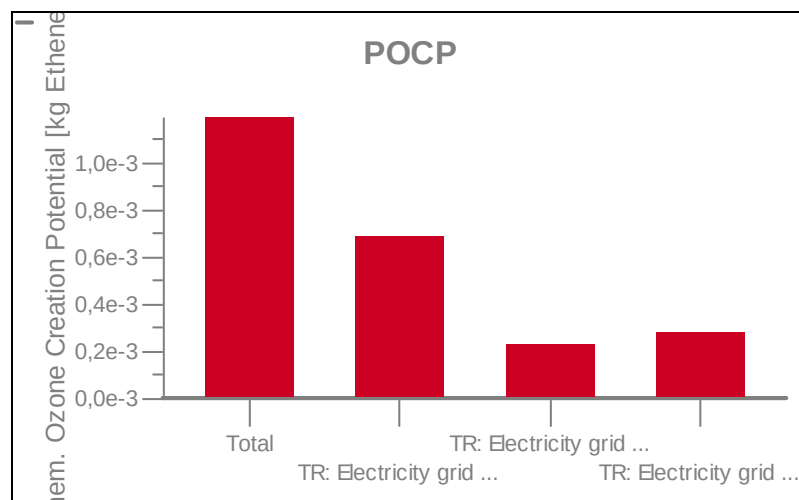


Figure 4.11 Photochemical ozone creation potential

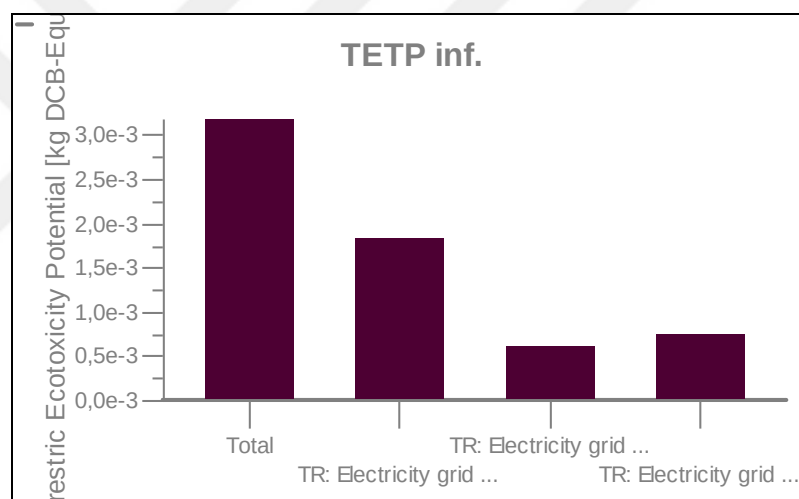


Figure 4.12 Terrestrial ecotoxicity potential

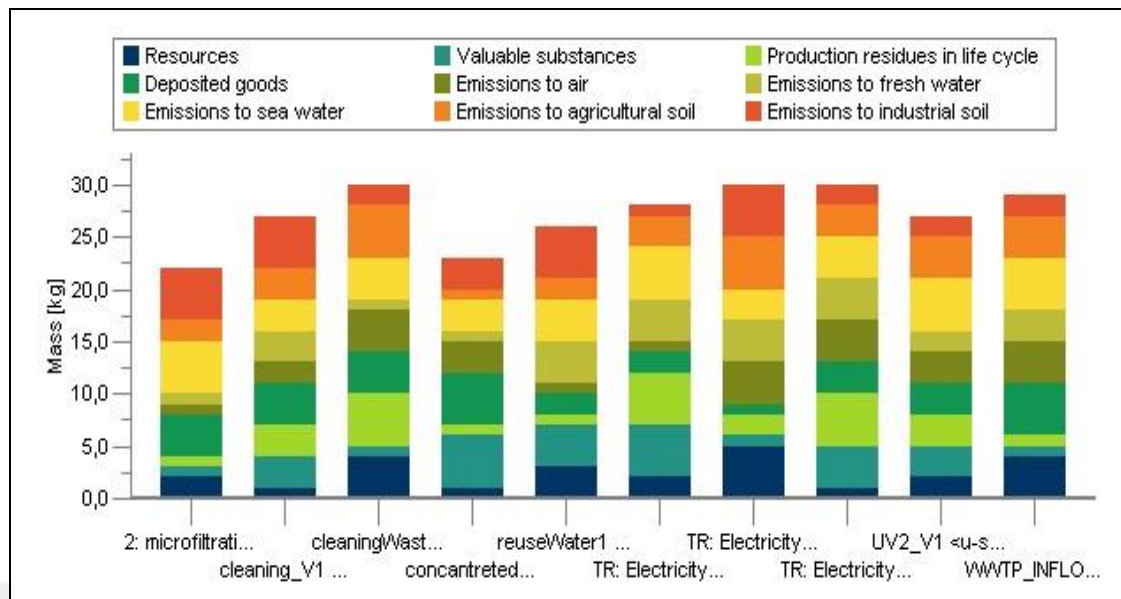


Figure 4.13 Massive contributions of primary units

4.1.2 Case 2

In Case 2, it was assumed that conventional domestic WWTP effluent treated with cartridge filter and ultrafiltration before reuse application. Energy source was chosen as electric grid-mix. Plan for this case study is given in Figure 4.14. In Figure 4.15 to 4.26, the whole system effects are seen according to environmental impact categories in GaBi software.

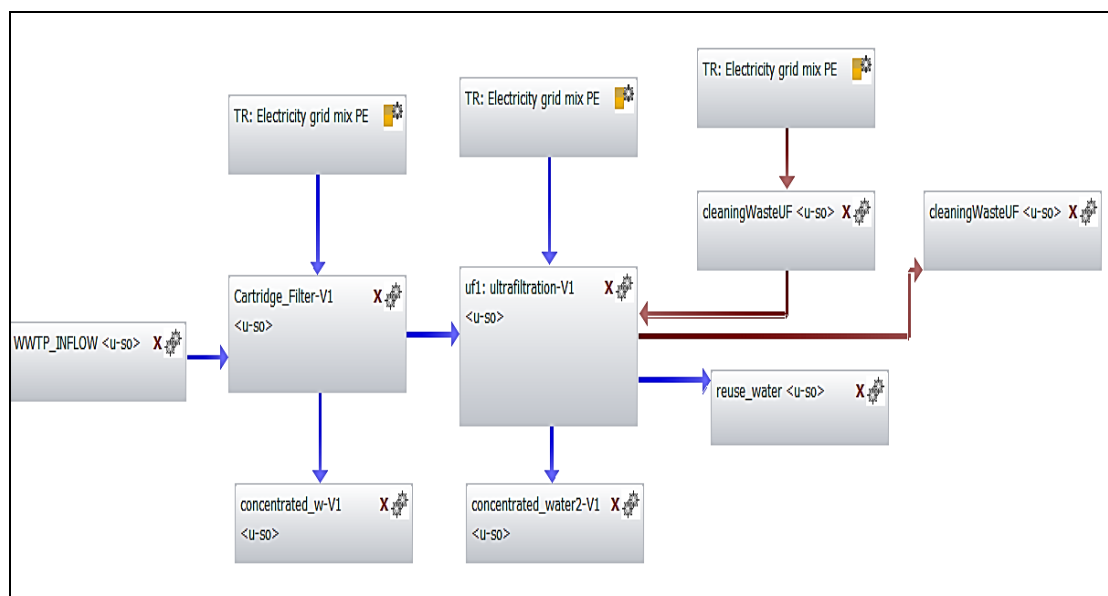


Figure 4.14 Plan for Case 2 – Scenario 1

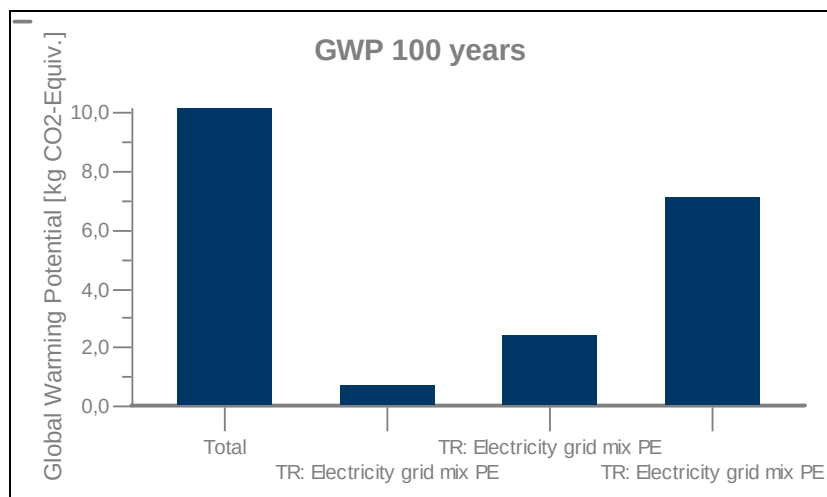


Figure 4.15 Global warming potential

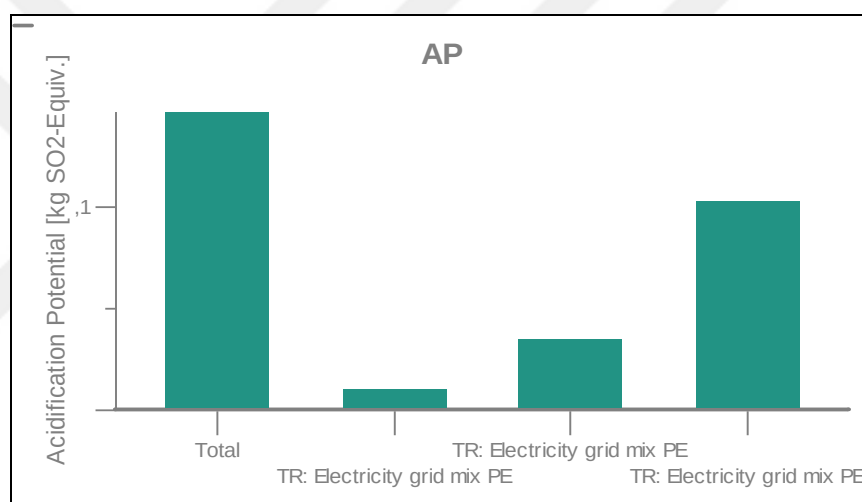


Figure 4.16 Acidification potential

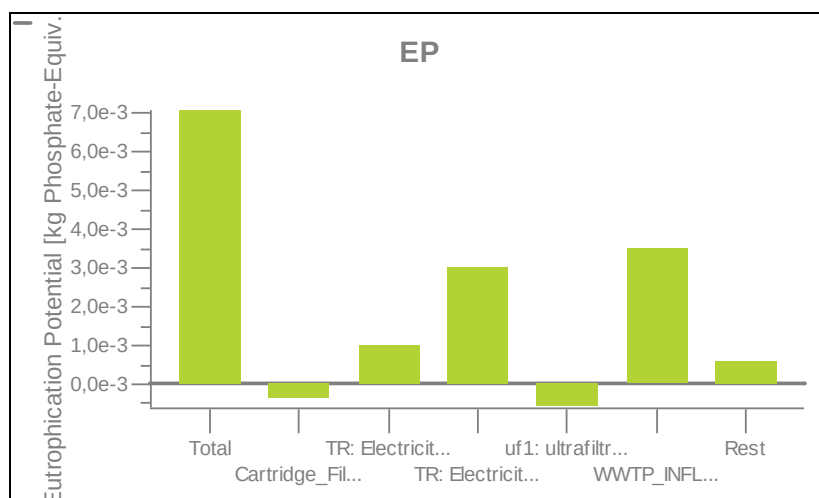


Figure 4.17 Eutrophication potential

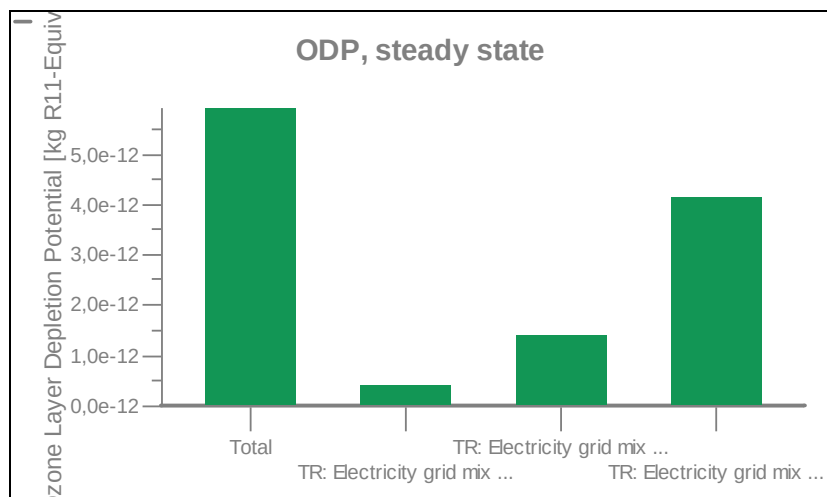


Figure 4.18 Ozone layer depletion potential

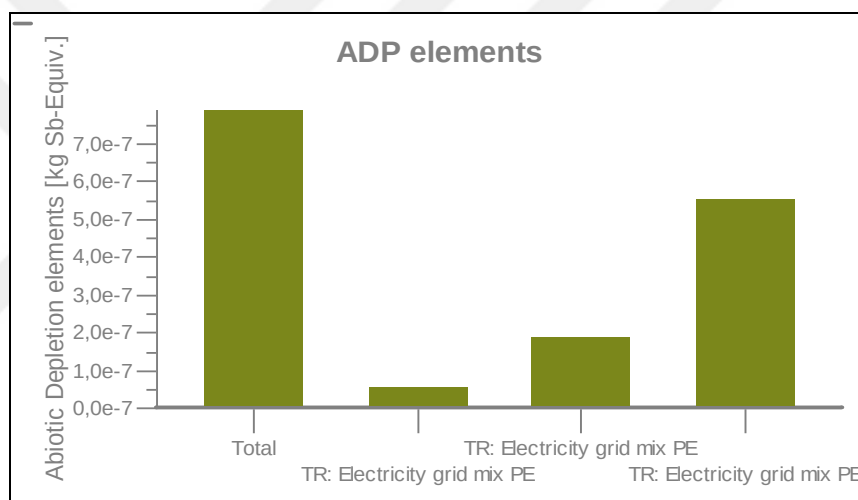


Figure 4.19 Abiotic depletion potential elements

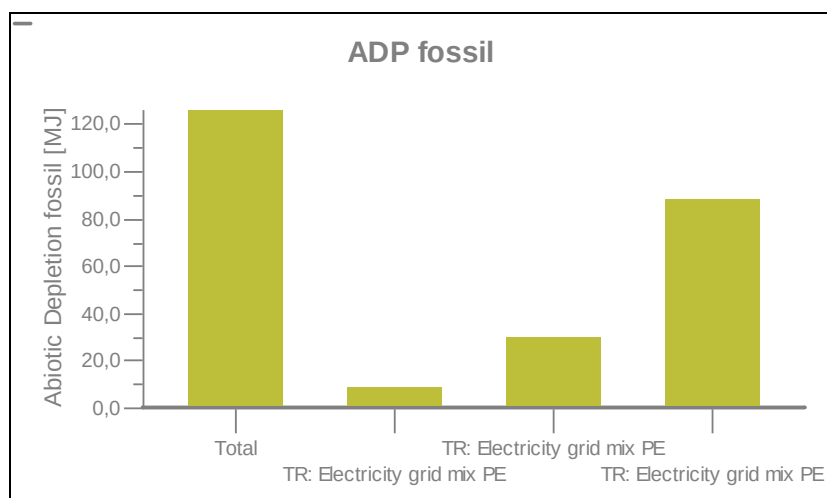


Figure 4.20 Abiotic depletion potential-fossil

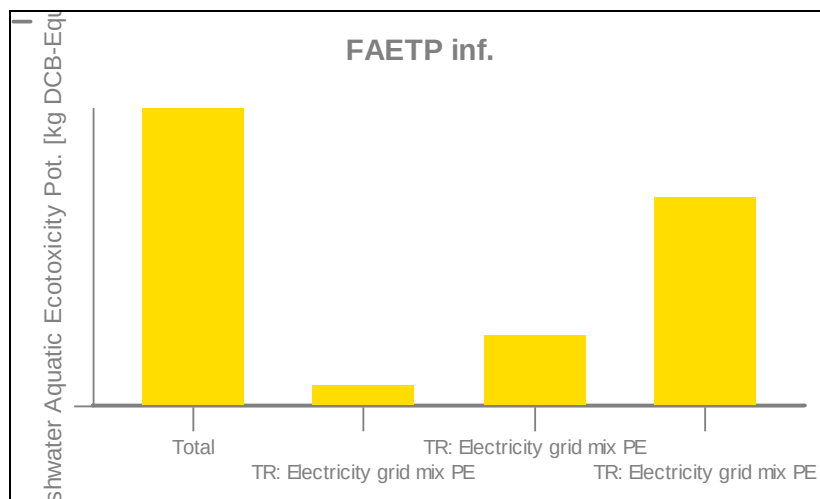


Figure 4.21 Freshwater aquatic ecotoxicity potential

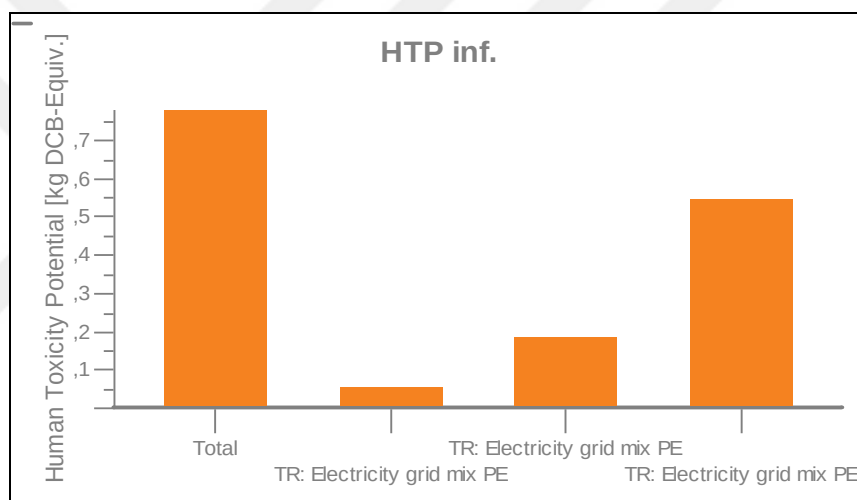


Figure 4.22 Human toxicity potential

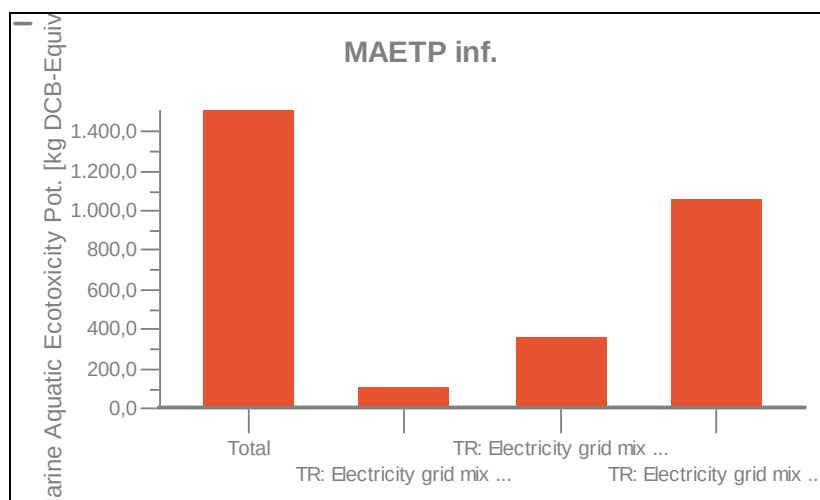


Figure 4.23 Marine aquatic potential

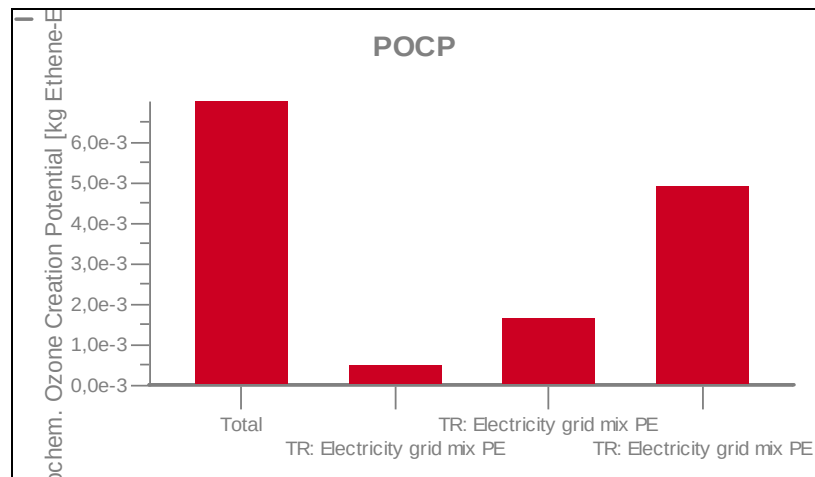


Figure 4.24 Photochemical ozone creation potential

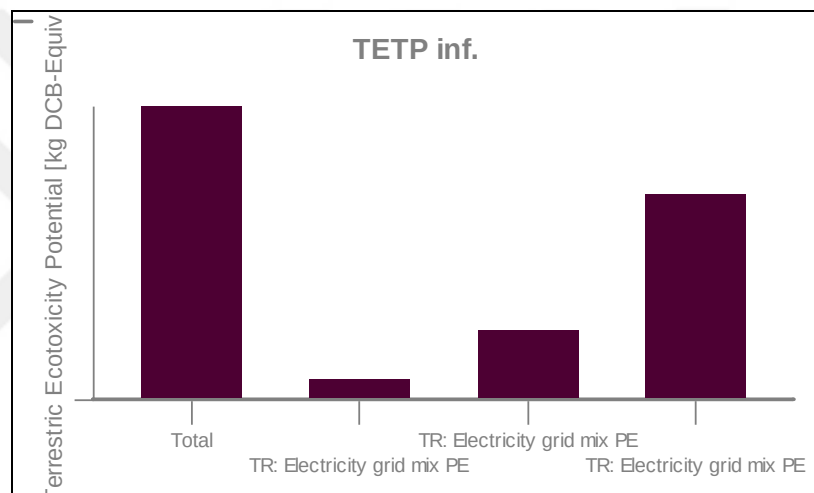


Figure 4.25 Terrestrial ecotoxicity potential

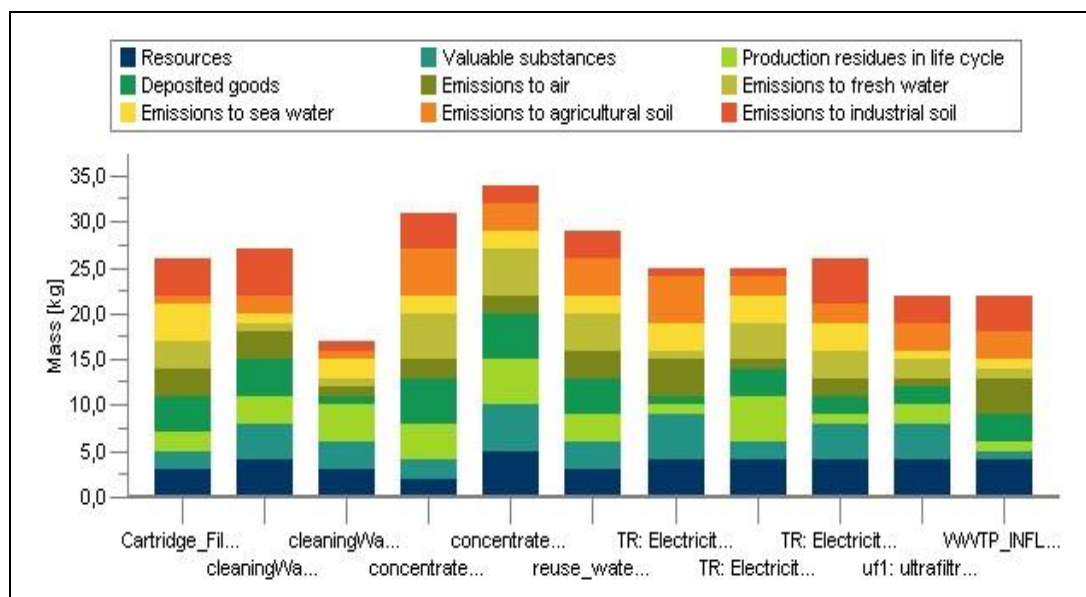


Figure 4.26 Massive contributions of primary units

4.1.3 Case 3

In Case 3, it was assumed that conventional domestic WWTP effluent treated with ultrafiltration before reuse application. Energy source was chosen electric grid-mix. Plan for this case study is given in Figure 4.27. The determined environmental effects of the case study are given in Figure 4.28 – Figure 4.39.

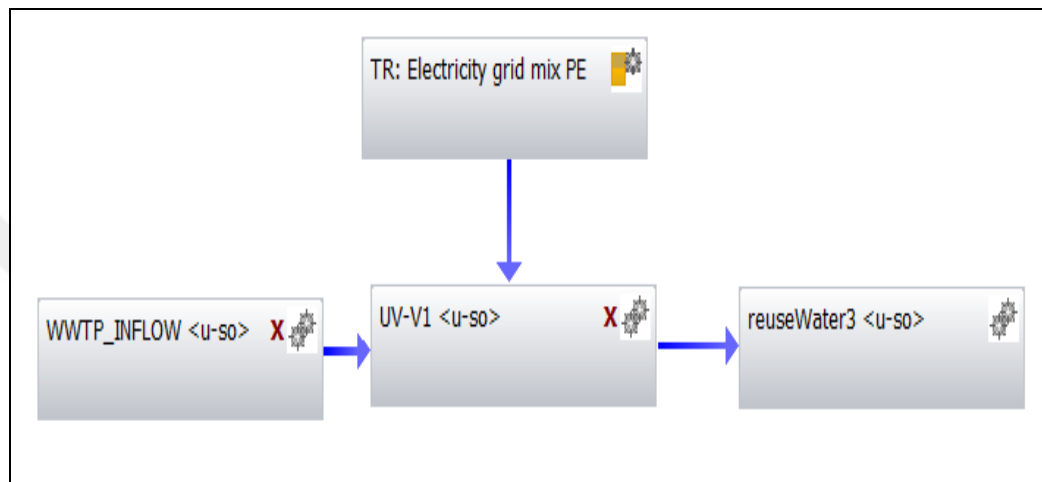


Figure 4.27 Plan for Case 3 – Scenario 1

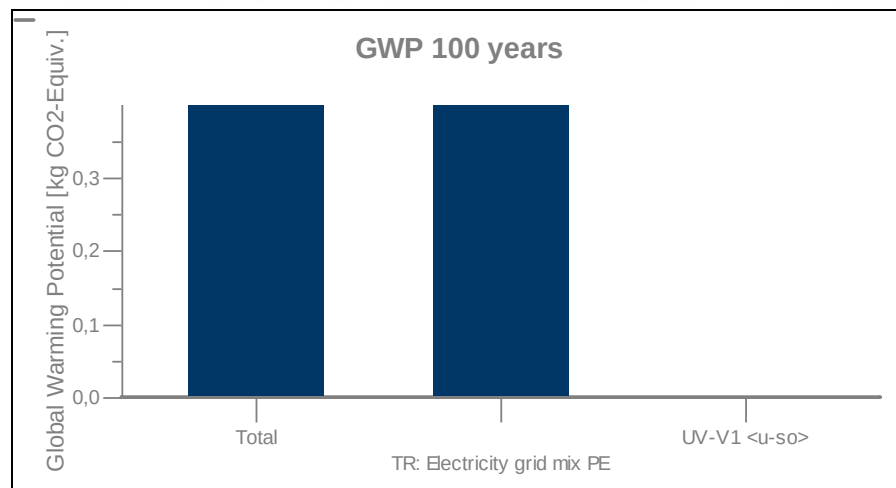


Figure 4.28 Global Warming Potential

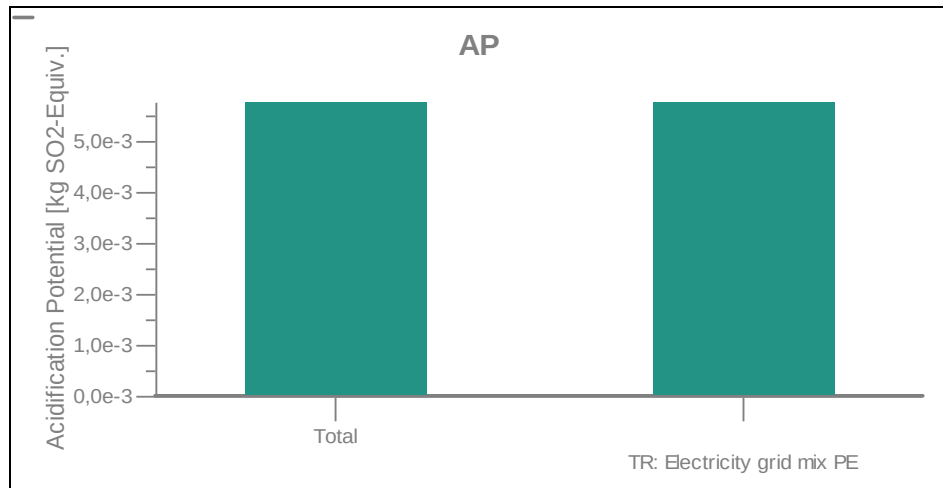


Figure 4.29 Acidification potential

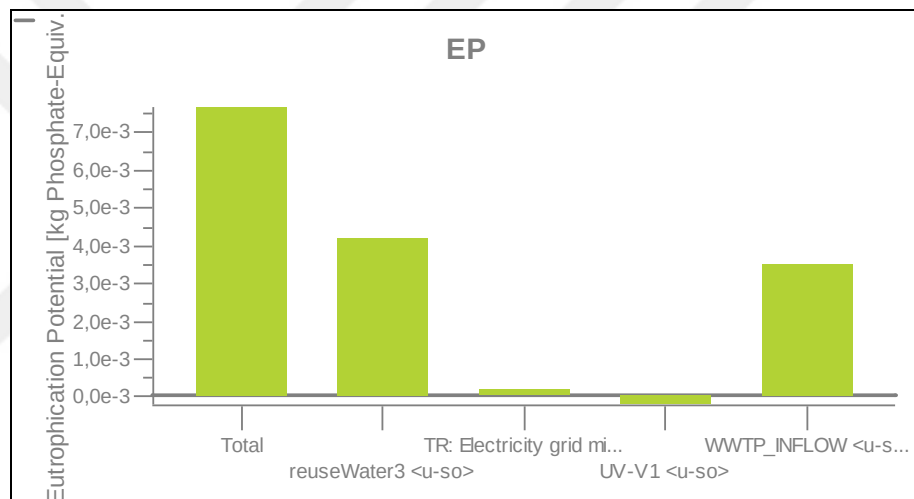


Figure 4.30 Eutrophication potential

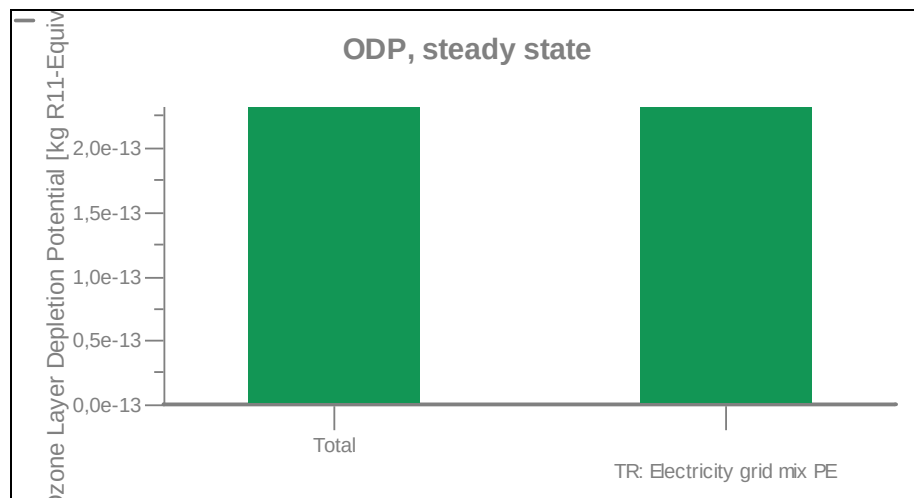


Figure 4.31 Ozone layer depletion potential

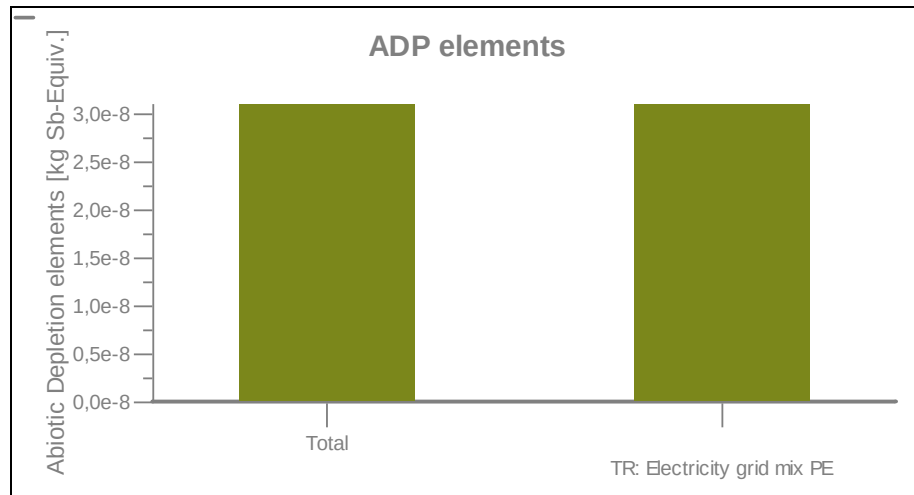


Figure 4.32 Abiotic depletion potential elements

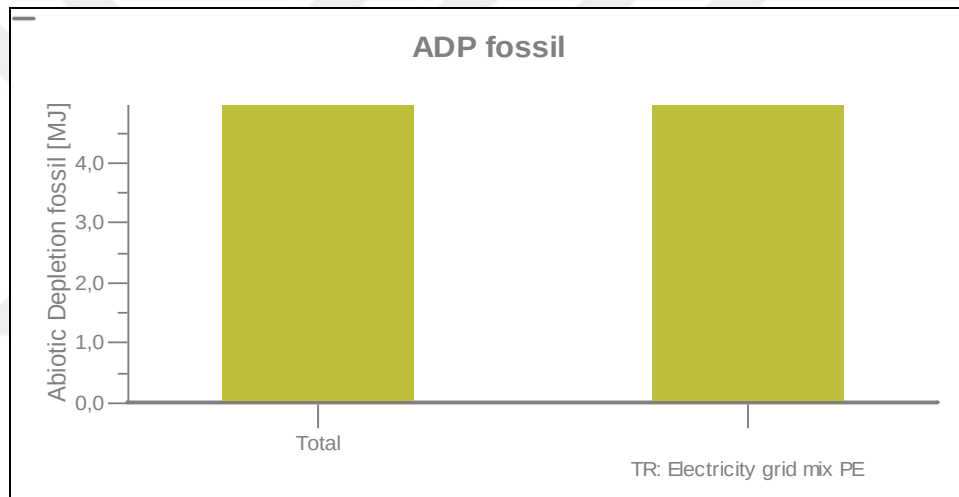


Figure 4.33 Abiotic depletion potential-fossil

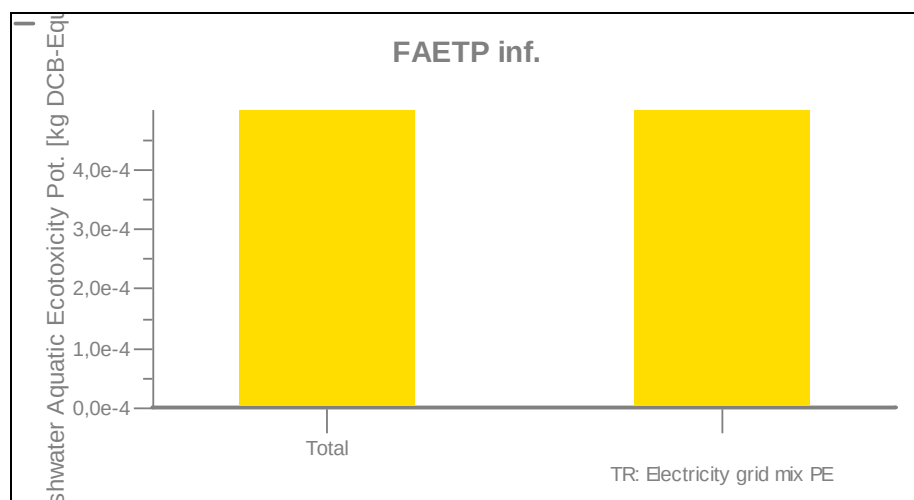


Figure 4.34 Freshwater aquatic ecotoxicity potential

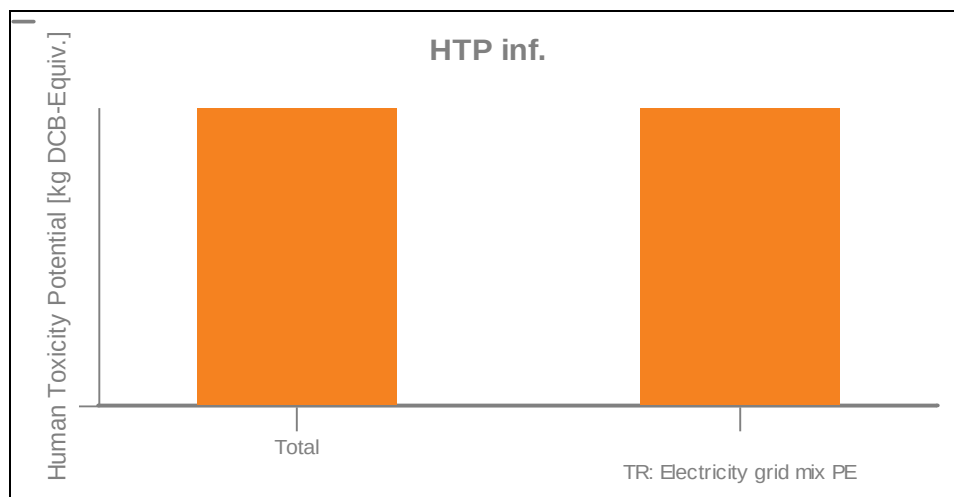


Figure 4.35 Human toxicity potential

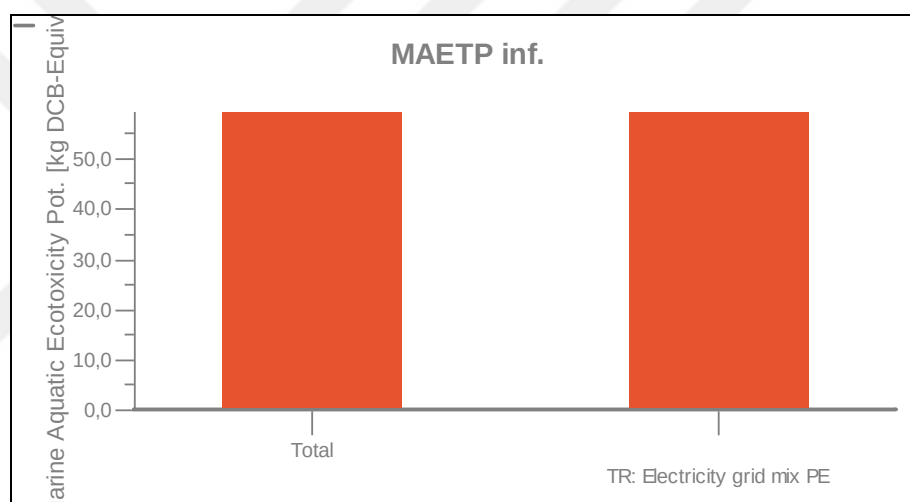


Figure 4.36 Marine aquatic potential

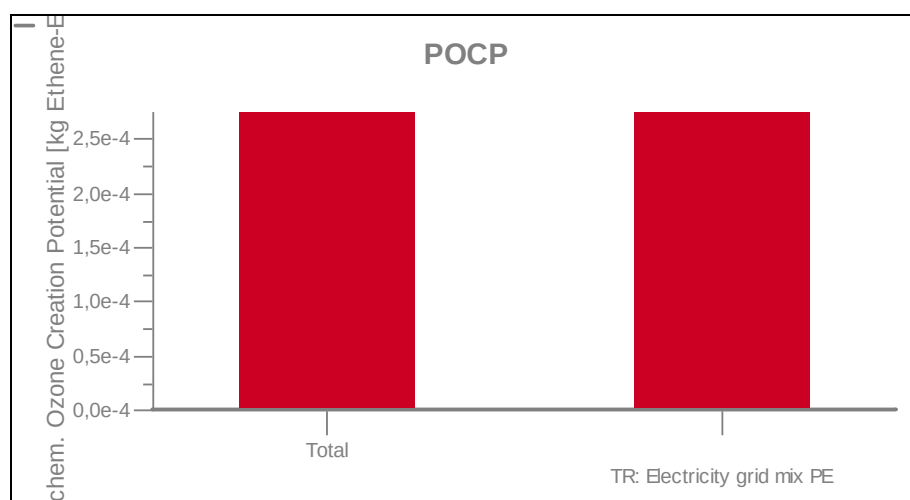


Figure 4.37 Photochemical ozone creation potential

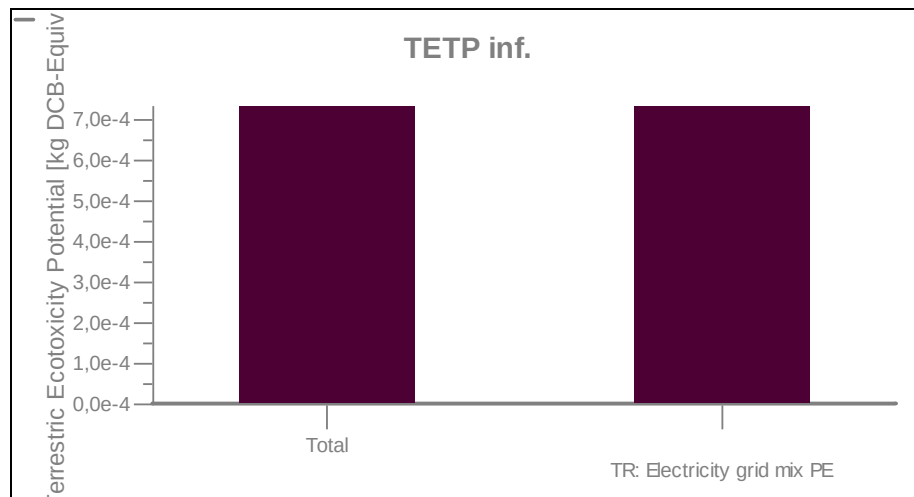


Figure 4.38 Terrestrial ecotoxicity potential

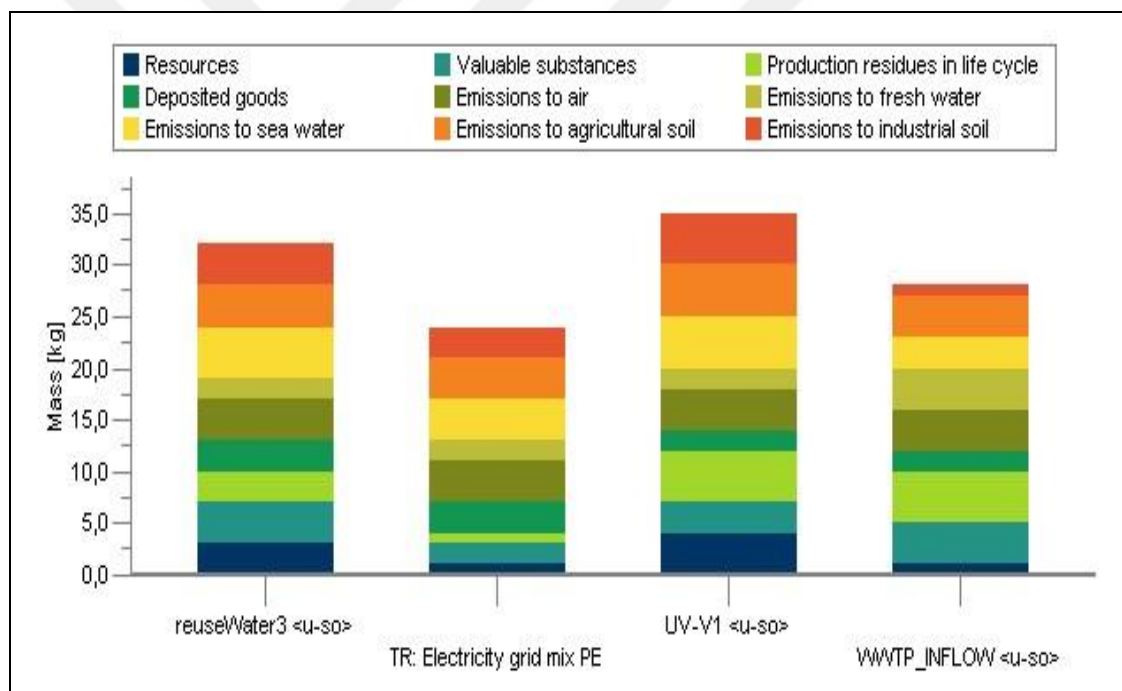


Figure 4.39 Massive contributions of primary units

The total environmental impacts of Scenario 1 were presented in Table 4.1 (electric grid mix as an energy source).

Table 4.1 The total environmental impacts of Scenario 1

Environmental Impact Categories	CASE-1 (MF+UV)	CASE-2 (CF+UF)	CASE-3 (UV)
Global Warming Potential [kg CO ₂ -Eq.]	1.73	10.1	0.399
Acidification Potential [kg SO ₂ -Eq.]	0.0249	0.146	5.75E-03
Eutrophication Potential [kg Phosphate-Eq.]	7.01E-03	7.05E-03	7.65E-03
Ozone Layer Depletion Potential [kg R11-Eq.]	1.01E-12	5.91E-12	2.32E-13
Abiotic Depletion elements [kg Sb-Eq.]	1.34E-07	7.88E-07	3.10E-08
Freshwater Aquatic Ecotoxicity Pot. [kg DCB-Eq.]	2.16E-03	0.0127	4.98E-04
Human Toxicity Potential [kg DCB-Eq.]	0.132	0.776	0.0306
Photochem. Ozone Creation Potential [kg Ethene-Eq.]	1.19E-03	6.98E-03	2.75E-04
Terrestrial Ecotoxicity Potential [kg DCB-Eq.]	3.17E-03	0.0186	7.32E-04

4.1.4 LCC

LCC calculation was also carried out by GaBi Software. Cost calculation was carried out for Scenario 1 ought to electric grid mix have more impact to the environment. The cost calculation results are given in Table 4.2.

Table 4.2 The cost calculation results

LCC results	CASE-1	CASE-2	CASE-3
(euro/m ³ treated water)	87.34	6.02	99.06

4.2 Results for Scenario 2

In Scenario 2, it was accepted that electricity from natural gas are used as an energy sources. In this scenario, three different cases were into consideration. The results are given in the following subsections.

4.2.1 Case 1

In Case 1, conventional domestic WWTP effluent treated with microfiltration and UV before reuse application. Energy source was chosen electricity from natural gas. Plan for this case study is given in Figure 4.40. The determined environmental effects of the case study are given in Figure 4.41 – Figure 4.52.

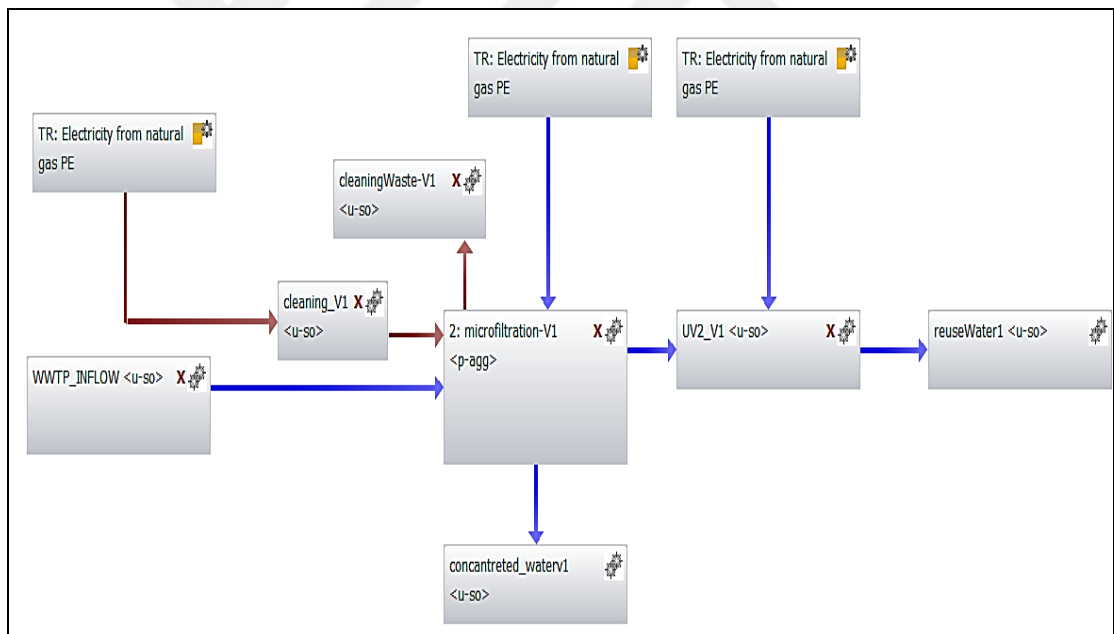


Figure 4.40 Plan for Case 1 – Scenario 2

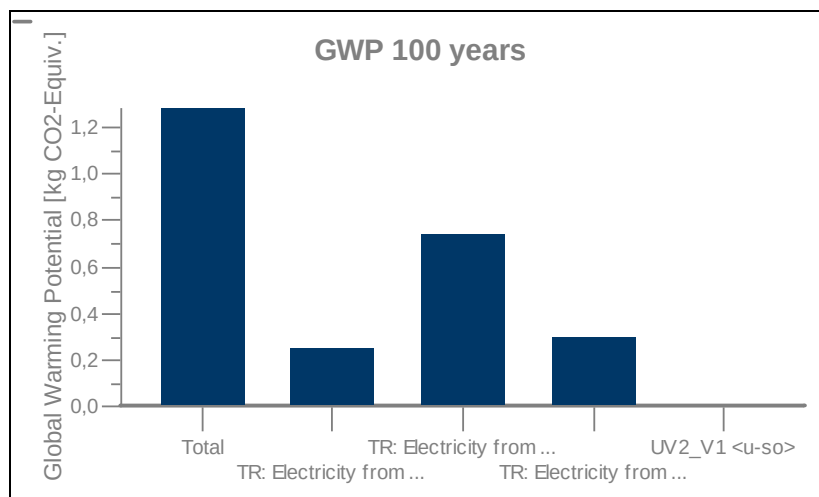


Figure 4.41 Global warming potential

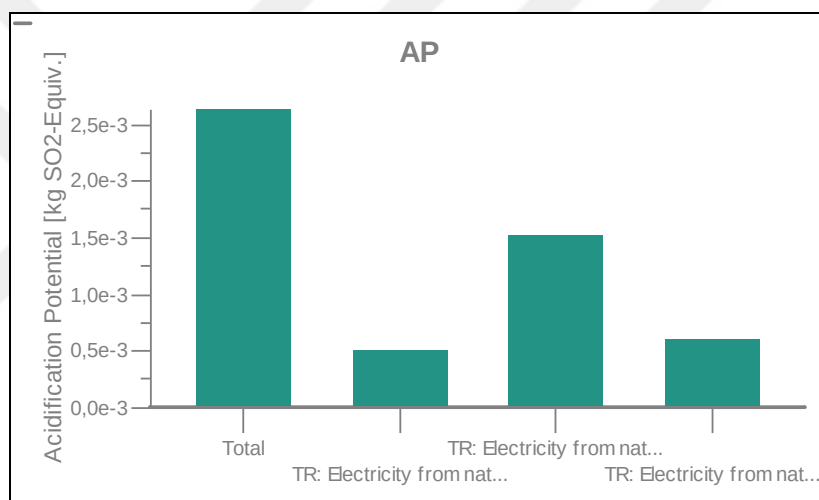


Figure 4.42 Acidification potential

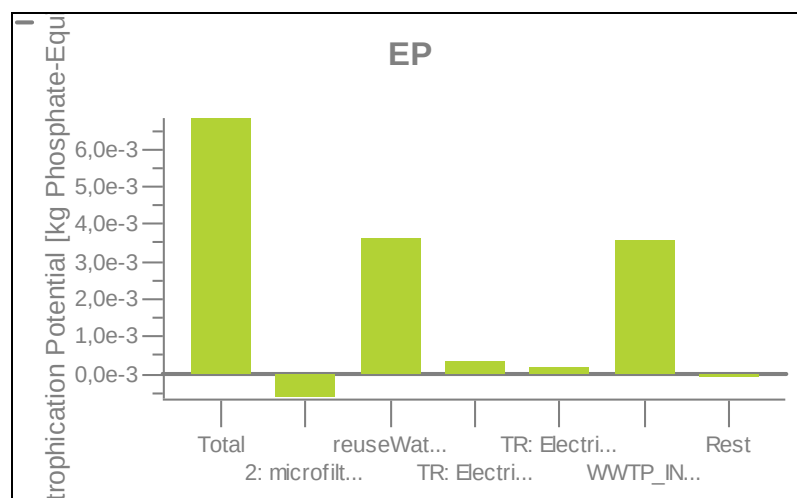


Figure 4.43 Eutrophication potential

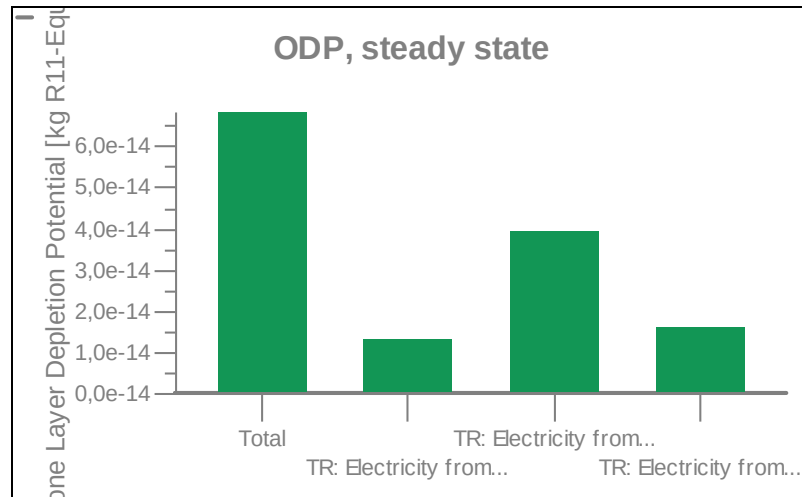


Figure 4.44 Ozone layer depletion potential

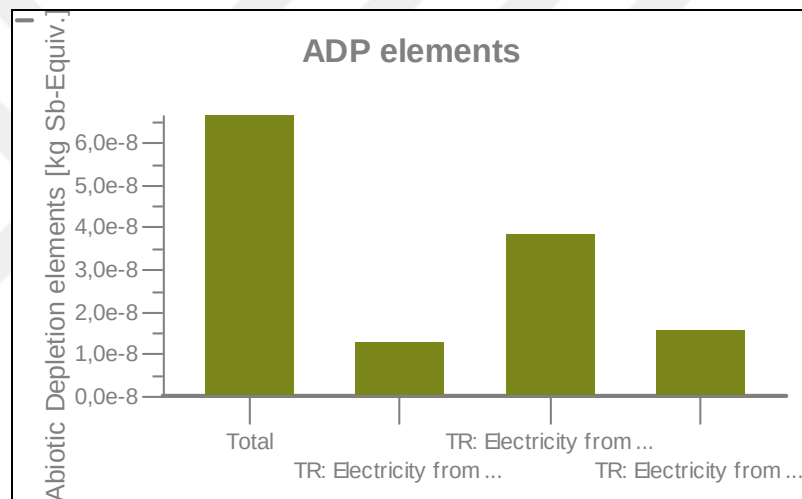


Figure 4.45 Abiotic depletion potential elements

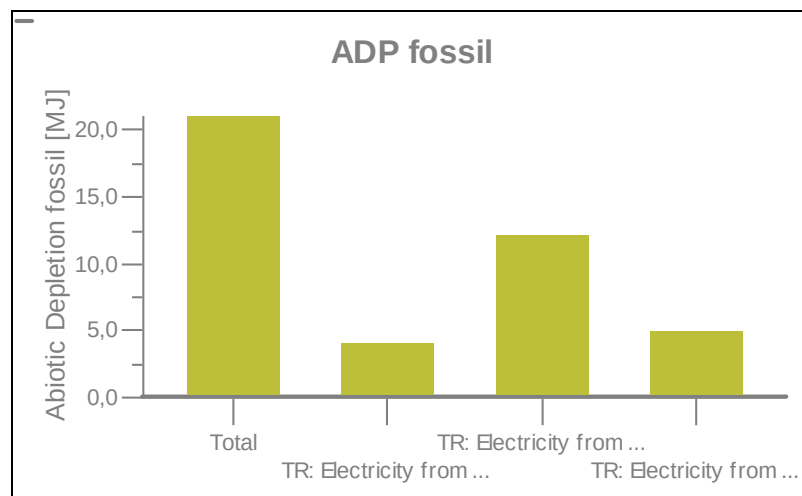


Figure 4.46 Abiotic depletion potential-fossil

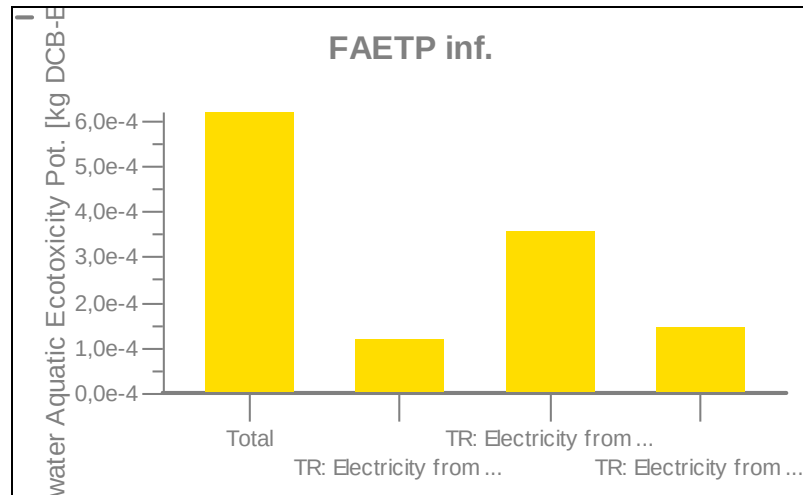


Figure 4.47 Freshwater aquatic ecotoxicity potential

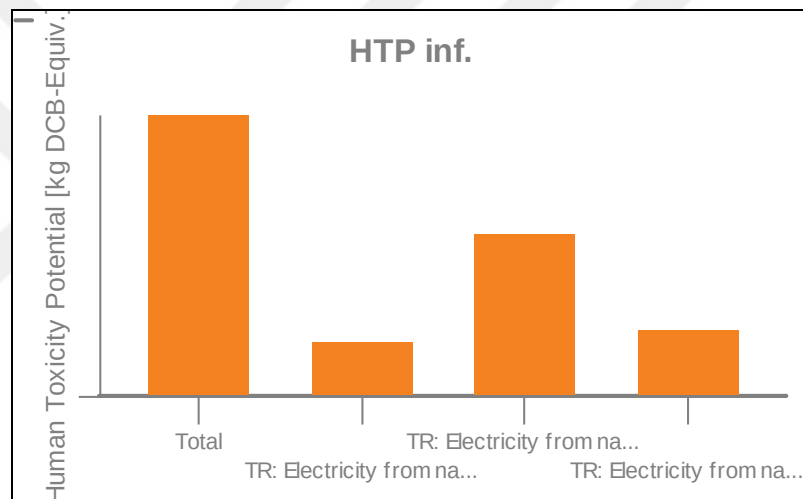


Figure 4.48 Human toxicity potential

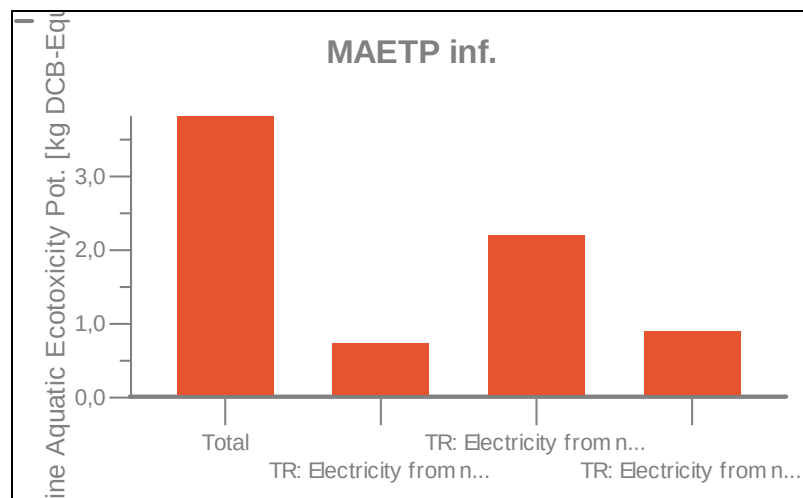


Figure 4.49 Marine aquatic potential

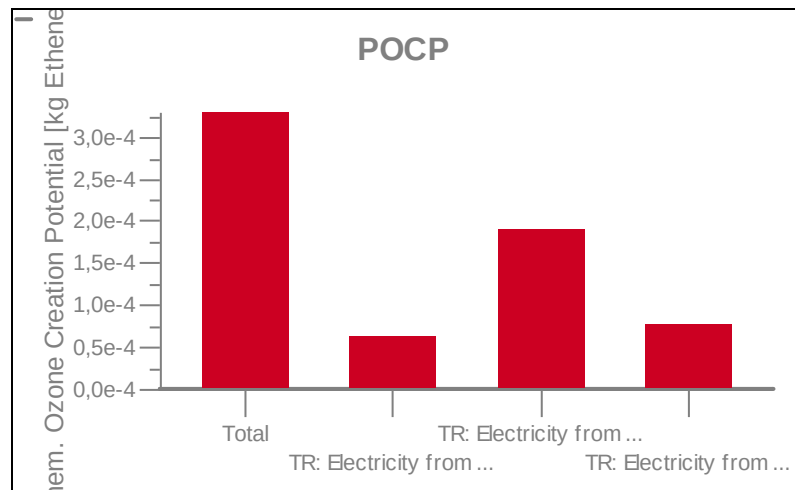


Figure 4.50 Photochem. ozone creation potential

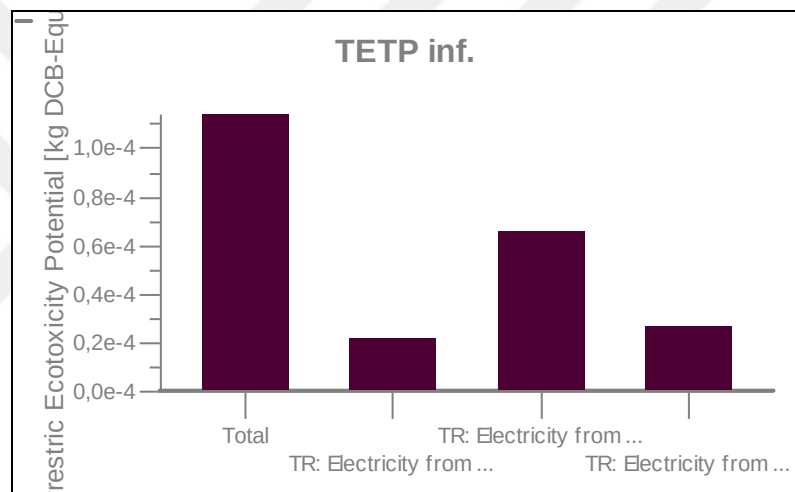


Figure 4.51 Terrestrial ecotoxicity potential

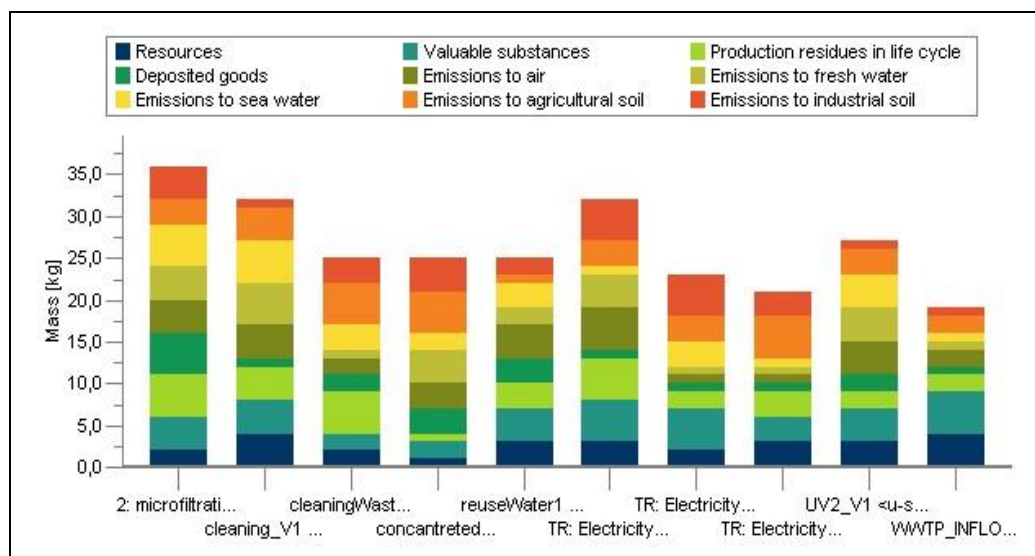


Figure 4.52 Massive contributions of primary units

4.2.2 Case 2

In Case 2, conventional domestic WWTP effluent treated with cartridge filter and ultrafiltration before reuse application. Energy source was chosen electricity from natural gas. Plan for this case study is given in Figure 4.53. The determined environmental effects of the case study are given in Figure 4.54 – Figure 4.65.

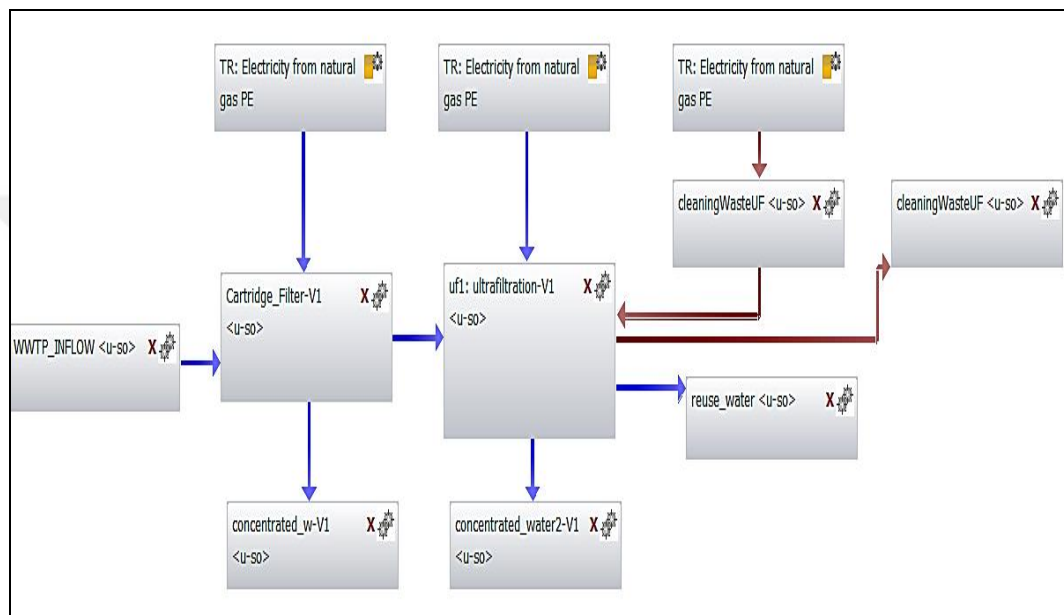


Figure 4.53 Plan for Case 2 – Scenario 2

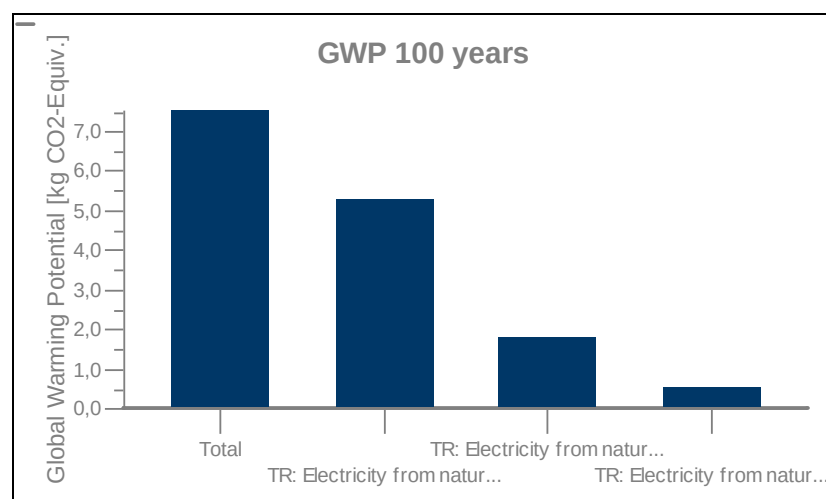


Figure 4.54 Global warming potential

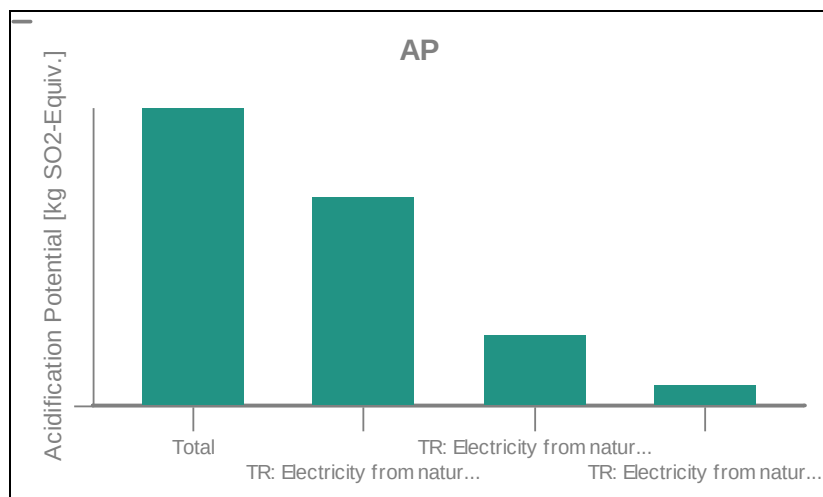


Figure 4.55 Acidification potential

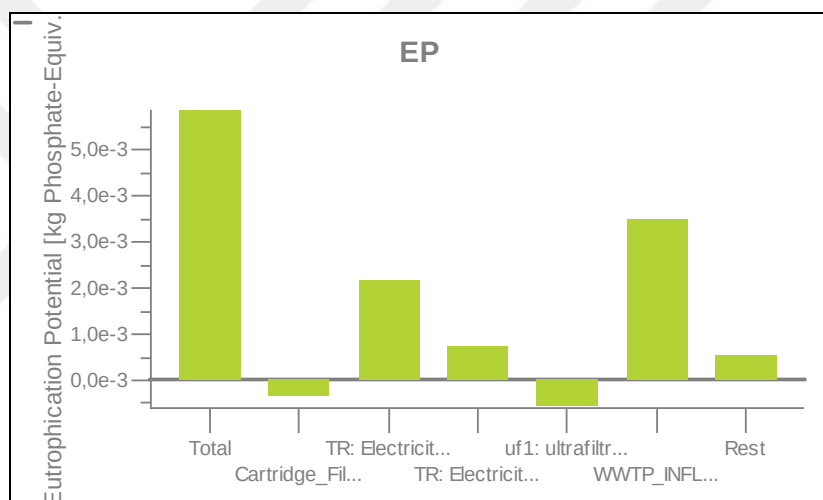


Figure 4.56 Eutrophication potential

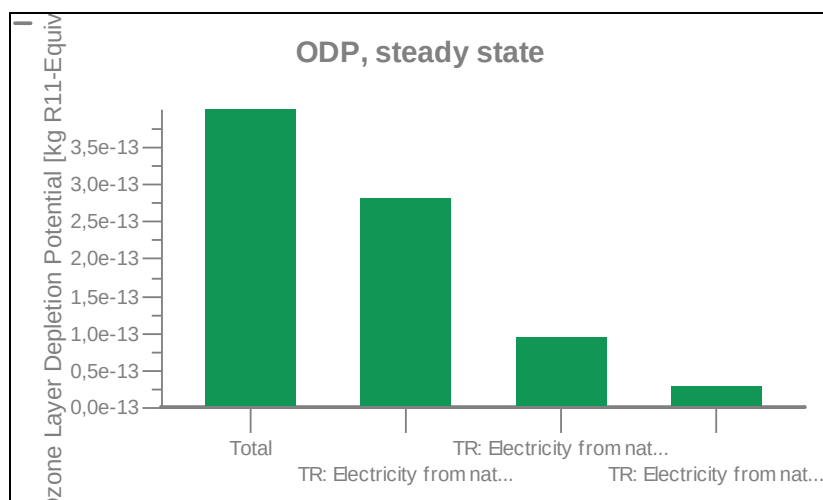


Figure 4.57 Ozone layer depletion potential

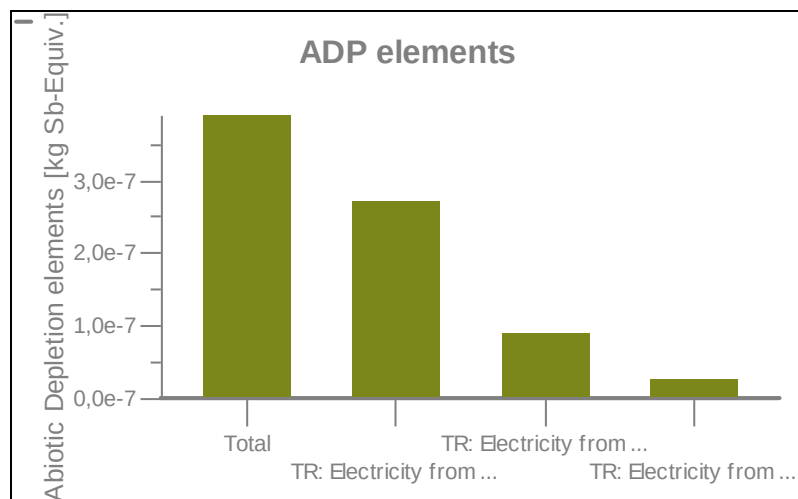


Figure 4.58 Abiotic depletion potential elements

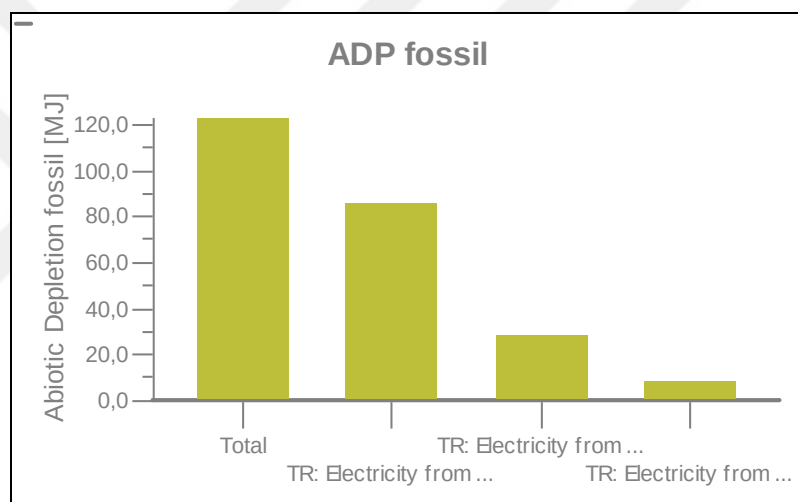


Figure 4.59 Abiotic depletion potential-fossil

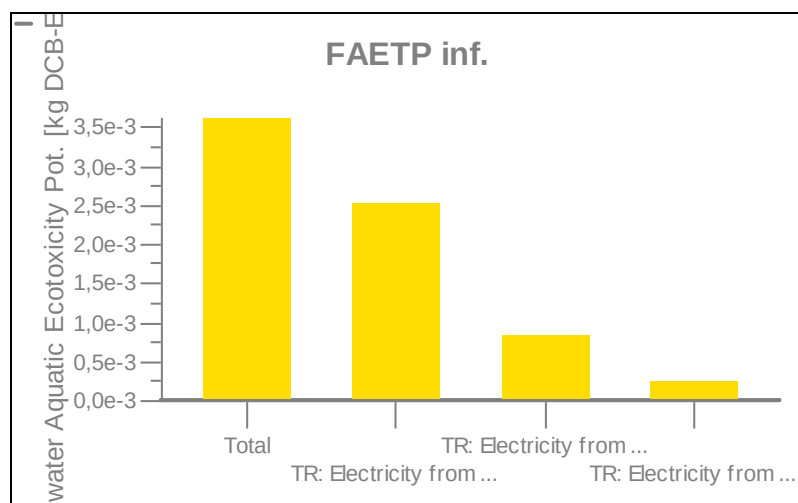


Figure 4.60 Freshwater aquatic ecotoxicity potential

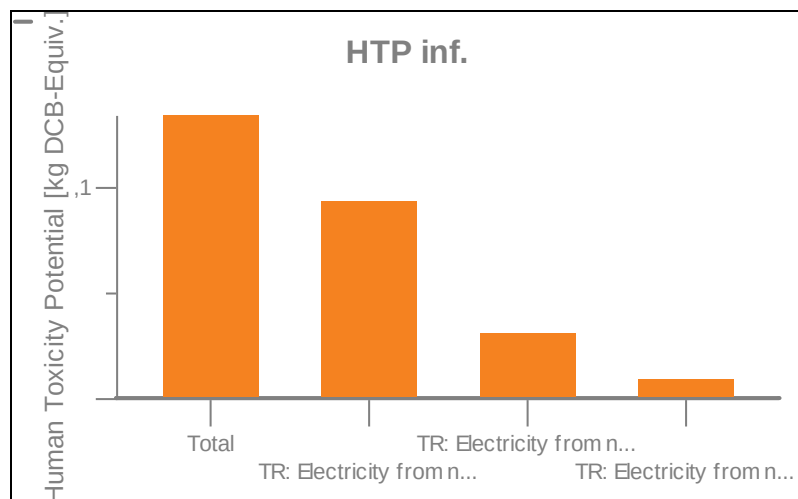


Figure 4.61 Human toxicity potential

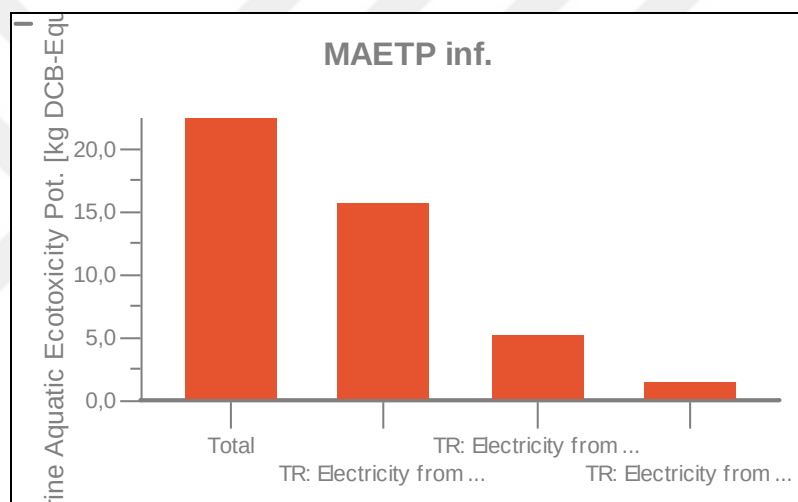


Figure 4.62 Marine aquatic potential

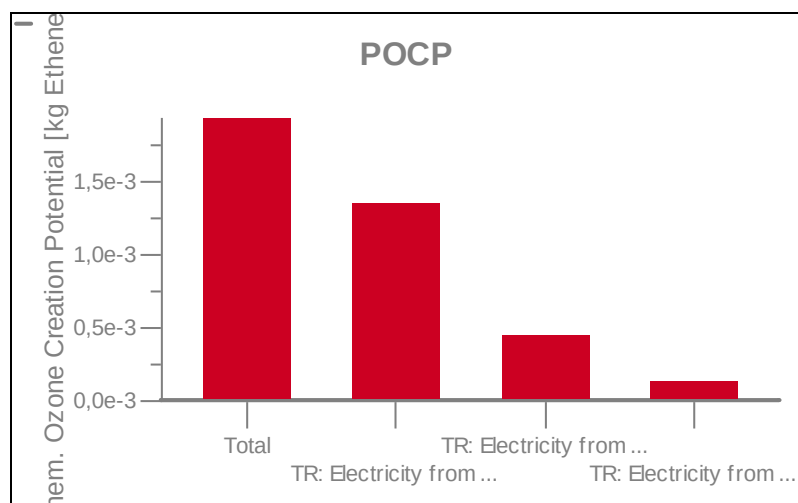


Figure 4.63 Photochemical ozone creation potential

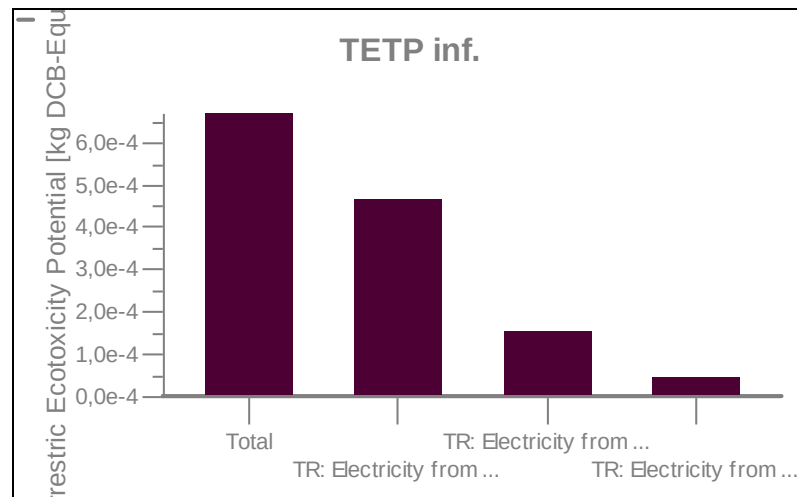


Figure 4.64 Terrestrial ecotoxicity potential

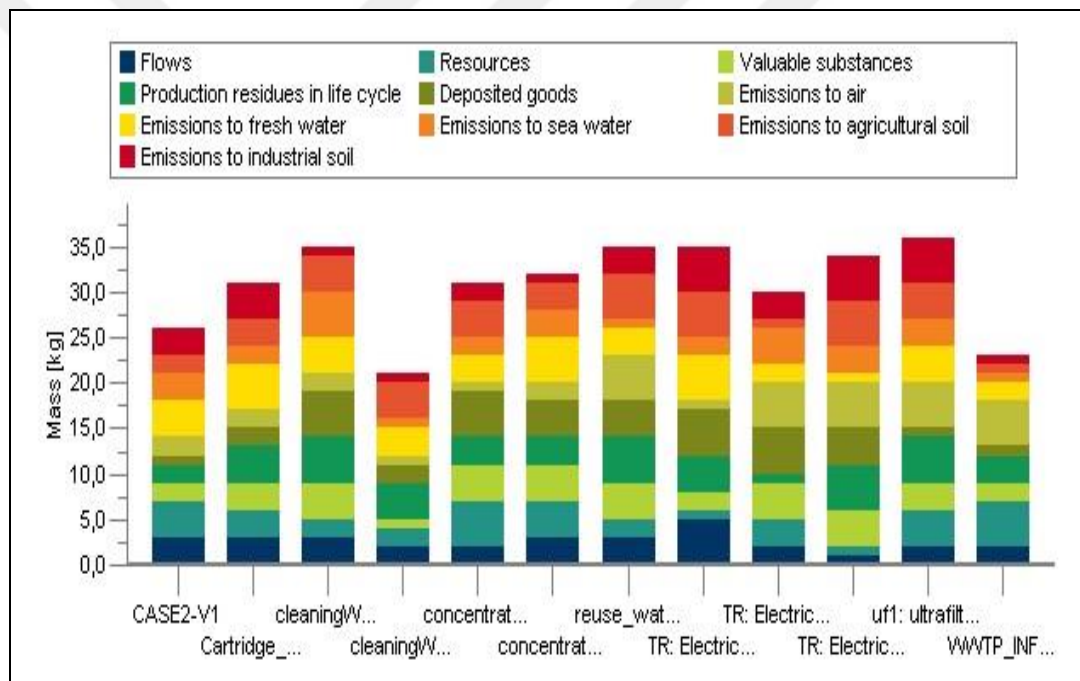


Figure 4.65 Massive contributions of primary units

4.2.3 Case 3

In Case 3, conventional domestic WWTP effluent treated with ultrafiltration membrane unit before reuse application. Energy source was chosen electricity from natural gas. Plan for this case study is given in Figure 4.66. The determined environmental effects of the case study are given in Figure 4.67 – Figure 4.78.

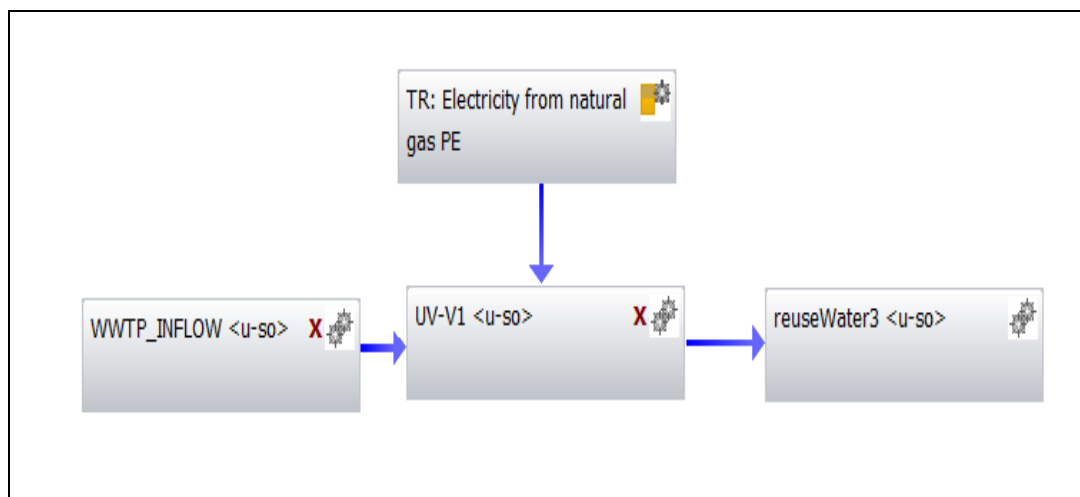


Figure 4.66 Plan for Case 3 – Scenario 2

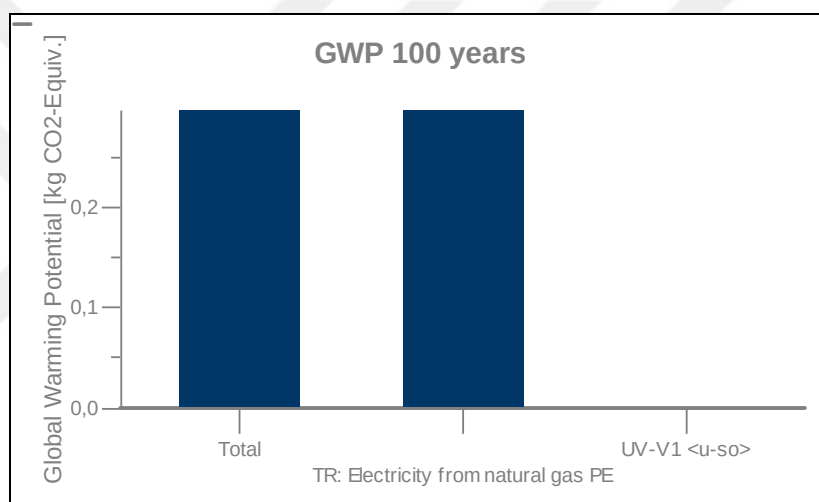


Figure 4.67 Global warming potential

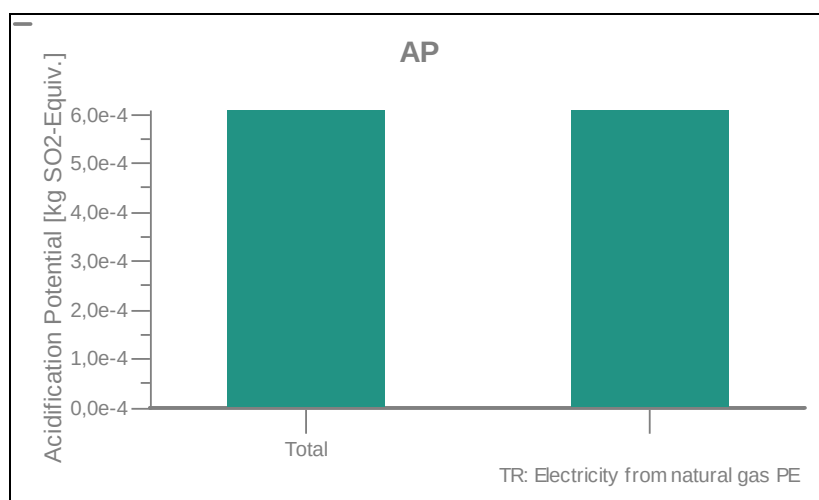


Figure 4.68 Acidification potential

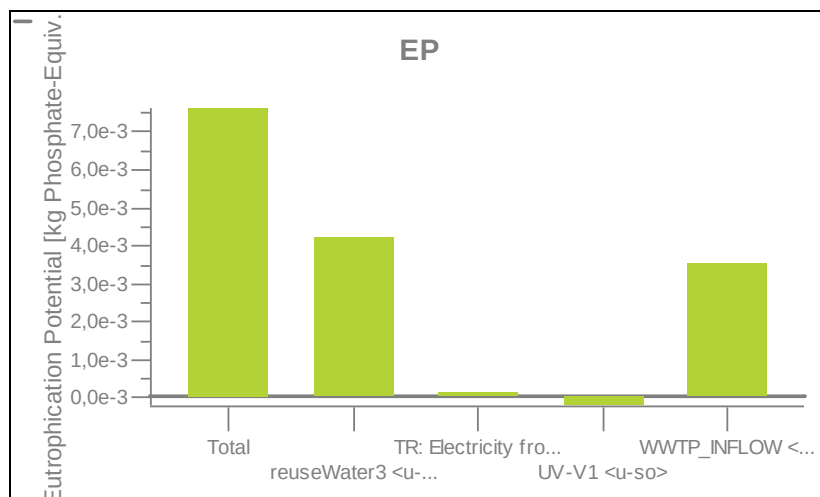


Figure 4.69 Eutrophication potential

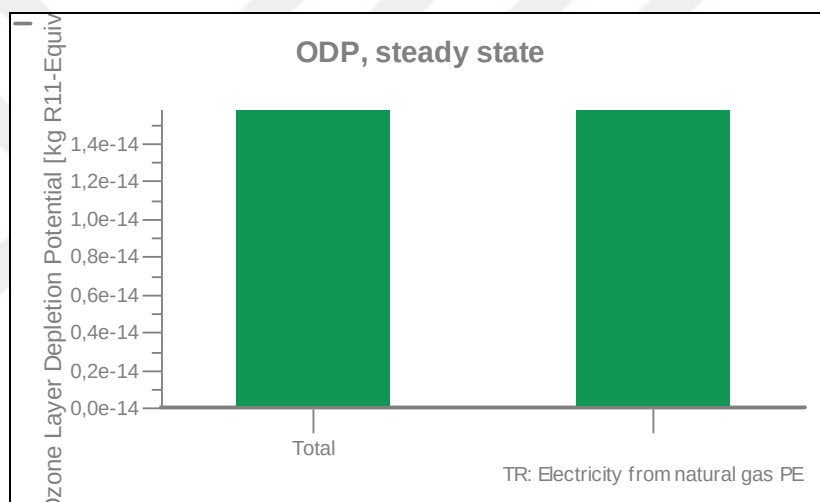


Figure 4.70 Ozone layer depletion potential

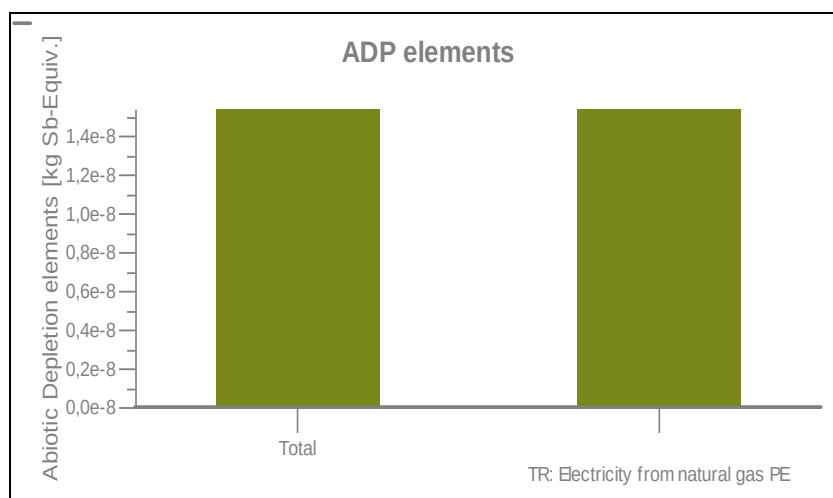


Figure 4.71 Abiotic depletion potential elements

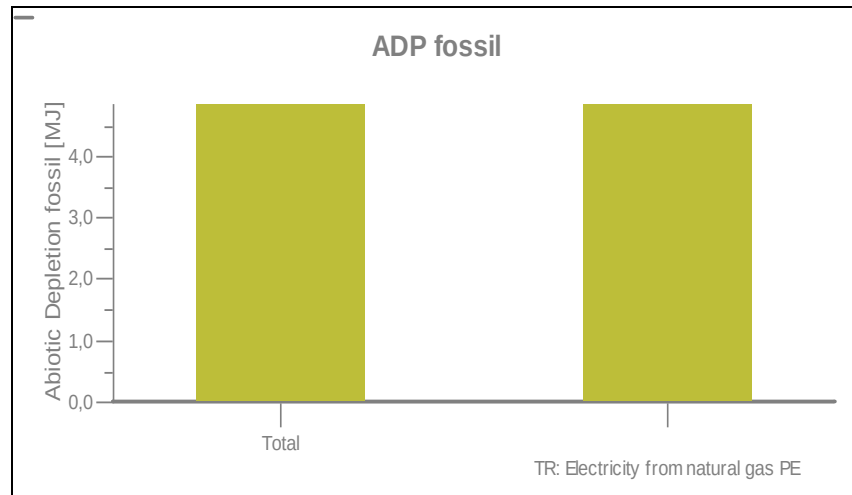


Figure 4.72 Abiotic depletion potential-fossil

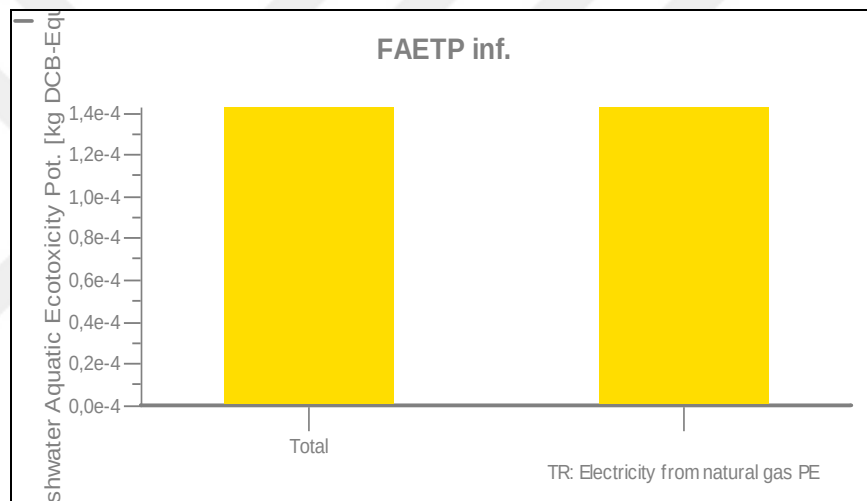


Figure 4.73 Freshwater aquatic ecotoxicity potential

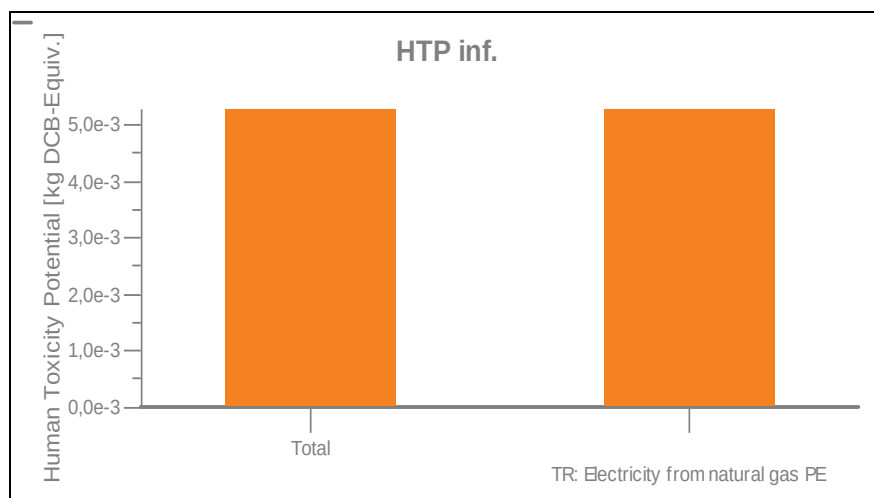


Figure 4.74 Human toxicity potential

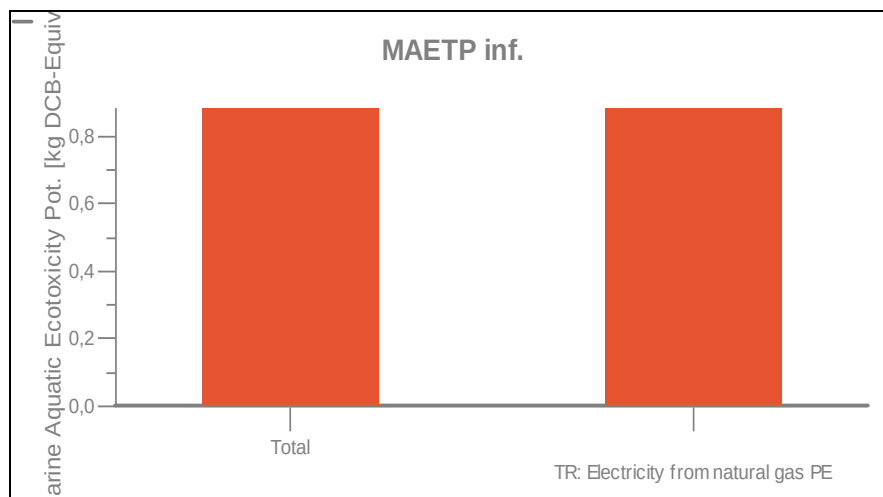


Figure 4.75 Marine aquatic potential

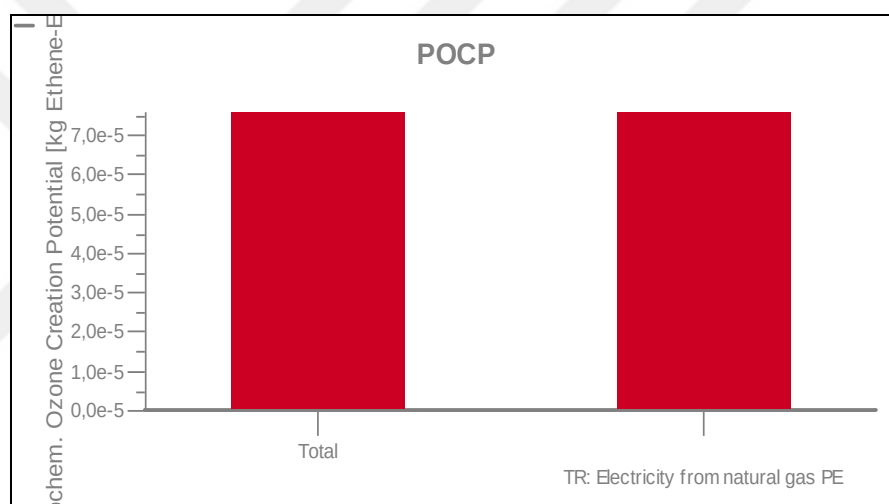


Figure 4.76 Photochemical ozone creation potential

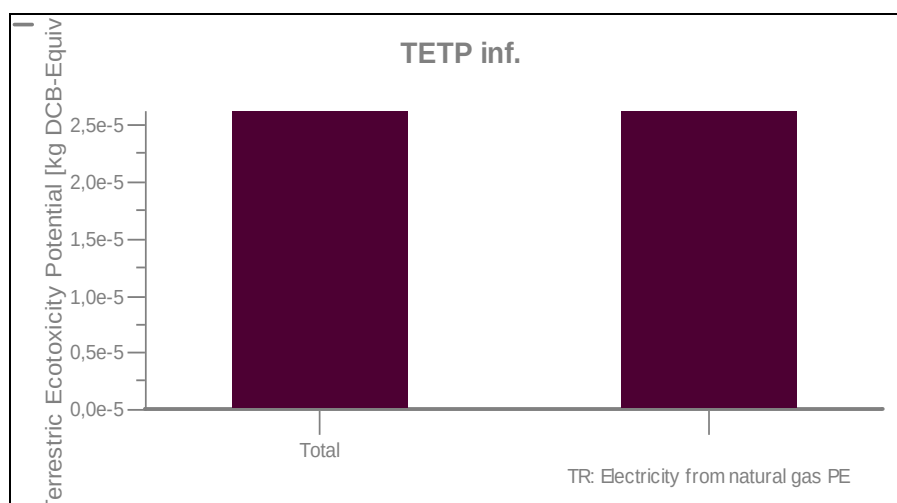


Figure 4.77 Terrestrial ecotoxicity potential

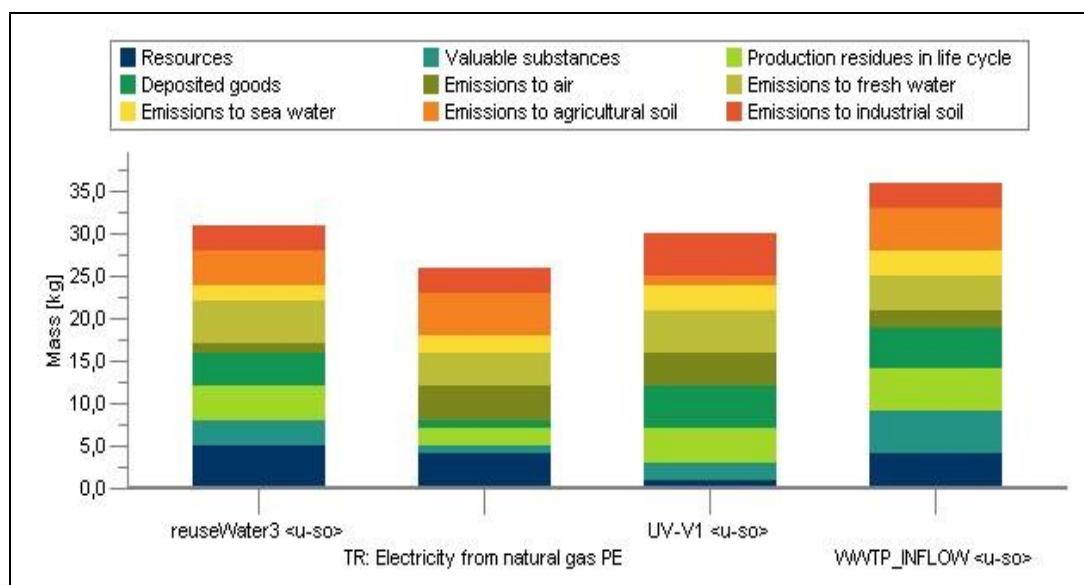


Figure 4.78 Massive contributions of primary units

The total environmental impacts of Scenario 2 are presented in Table 4.3 (electricity from natural gas as an energy source).

Table 4.3 The total environmental impacts of Scenario 2

Environmental Impact Categories	CASE-1 (MF+UV)	CASE-2 (CF+UF)	CASE-3 (UV)
Global Warming Potential [kg CO ₂ -Eq.]	1.28	7.5	0.295
Acidification Potential [kg SO ₂ -Eq.]	2.63E-03	0.0154	6.06E-04
Eutrophication Potential [kg Phosphate-Eq.]	6.80E-03	5.85E-03	7.60E-03
Ozone Layer Depletion Potential [kg R11-Eq.]	6.81E-14	3.99E-13	1.57E-14
Abiotic Depletion elements [kg Sb-Eq.]	6.62E-08	3.88E-07	1.53E-08
Freshwater Aquatic Ecotoxicity Pot. [kg DCB-Eq.]	6.16E-04	3.61E-03	1.42E-04
Human Toxicity Potential [kg DCB-Eq.]	0.0228	1.34E-01	5.26E-03
Photochemical Ozone Creation Potential [kg Ethene-Eq.]	3.28E-04	1.92E-03	7.57E-05
Terrestrial Ecotoxicity Potential [kg DCB-Eq.]	1.14E-04	6.66E-04	2.62E-05

4.3 Evaluation of the Results

To compare the results of Scenario 1 and 2, all determined environmental impacts of the case studies are given in Table 4.4. The results are also given as graphs (Figure 4.79 – 4.90) and the abbreviations used in these graphs are given in Table 4.5.

Table 4.4 The total environmental impacts of Scenario 1 and 2

Environmental Impact Categories	Scenario 1 (electric-grid mix)			Scenario 2 (natural gas)		
	CASE-1 (MF+UV)	CASE-2 (CF+UF)	CASE-3 (UV)	CASE-1 (MF+UV)	CASE-2 (CF+UF)	CASE-3 (UV)
Global Warming Potential [kg CO ₂ -Eq.]	1.73	10.1	0.399	1.28	7.5	0.295
Acidification Potential [kg SO ₂ -Eq.]	0.0249	0.146	5.75E-03	2.63E-03	0.0154	6.06E-04
Eutrophication Potential [kg Phosphate-Eq.]	7.01E-03	7.05E-03	7.65E-03	6.80E-03	5.85E-03	7.60E-03
Ozone Layer Depletion Potential [kg R11-Eq.]	1.01E-12	5.91E-12	2.32E-13	6.81E-14	3.99E-13	1.57E-14
Abiotic Depletion elements [kg Sb-Eq.]	1.34E-07	7.88E-07	3.10E-08	6.62E-08	3.88E-07	1.53E-08
Freshwater Aquatic Ecotoxicity Potential [kg DCB-Eq.]	2.16E-03	0.0127	4.98E-04	6.16E-04	3.61E-03	1.42E-04
Human Toxicity Potential [kg DCB-Eq.]	0.132	0.776	0.0306	0.0228	1.34E-01	5.26E-03
Photochemical Ozone Creation Potential [kg Ethene-Eq.]	1.19E-03	6.98E-03	2.75E-04	3.28E-04	1.92E-03	7.57E-05
Terrestrial Ecotoxicity Potential [kg DCB-Eq.]	3.17E-03	0.0186	7.32E-04	1.14E-04	6.66E-04	2.62E-05

Table 4.5 Abbreviations used in the comparison graphics

Abbreviations	Explanation
Case 1-S1	Case 1 (MF+UV) - Scenario 1 electric-grid mix
Case 2-S1	Case 2 (CF+UF) - Scenario 1 electric-grid mix
Case 3-S1	Case 3 (UV) - Scenario 1 electric-grid mix
Case 1-S2	Case 1 (MF+UV) - Scenario 2 Natural Gas
Case 2-S2	Case 2 (CF+UF) -Scenario 2 Natural Gas
Case 3-S2	Case 3 (UV) - Scenario 2 Natural Gas

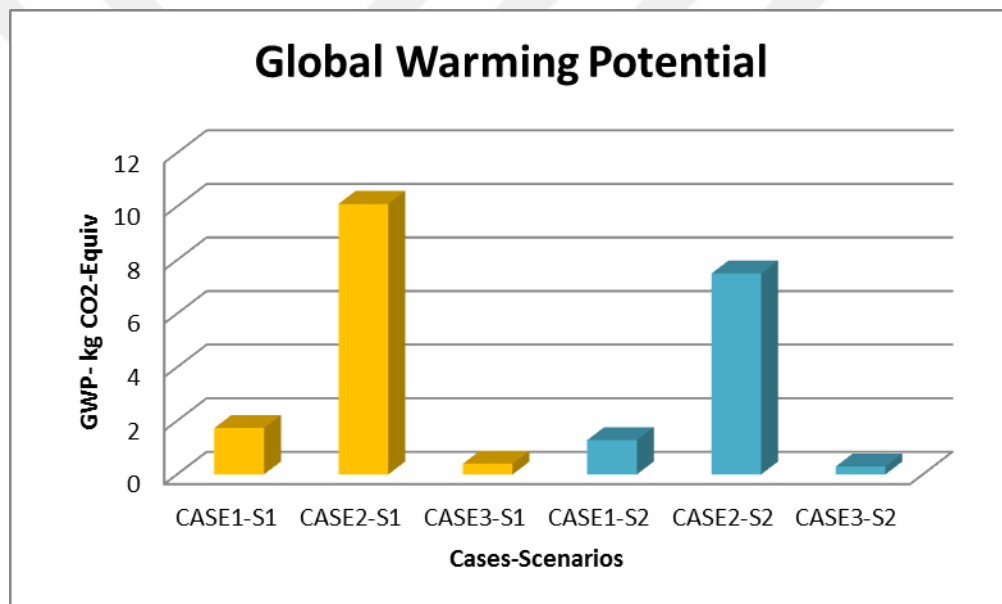


Figure 4.79 Comparison the results of global warming effects

According to Figure 4.79, Case 3 is clearly the most environmental friendly reuse application for both scenarios. It means that UV treatment is less environmental impact than the other cases and this result closely followed by Microfiltration and UV combination (Case 1) alternative. The chart also revealed energy source change effect on reuse application to environmental for Global Worming Potential. Case 1 – Case 3 has affected smaller than Case 2 which has relatively more energy consumption than the others. The results for Case 3 compared one of the previous studies (Meneses-Pasqualino et al., 2010) functional unit is same with the thesis. The

article is about UV and other disinfection alternatives for agricultural usage. The result is much lower than the thesis result because the energy need for UV is almost half of this thesis therefore specially GWP and some other impact categories have lesser than the thesis value since energy consumption is the most important source of the pollutions when it comes to treatment for reuse applications. The energy need changes for developer to developer, the chosen value for each process for this thesis selected from supplier brochures.

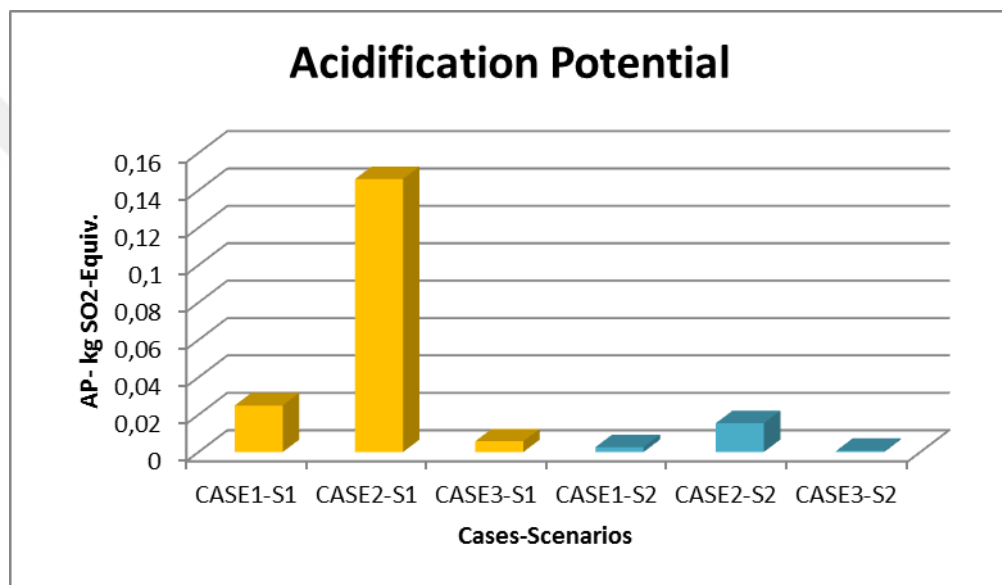


Figure 4.80 Comparison the results of acidification potential effects

It can be seen from Figure 4.80 that Case 3 for Scenario 2 is clearly the most environmentally friendly reuse application for the acidification potential point of view. Case 1 for Scenario 2 also has a small impact. The chart also revealed energy source change effects significant on Acidification Potential (AP). Electric grid mix usage as an energy source has a drastic effect on AP comparing to natural gas.

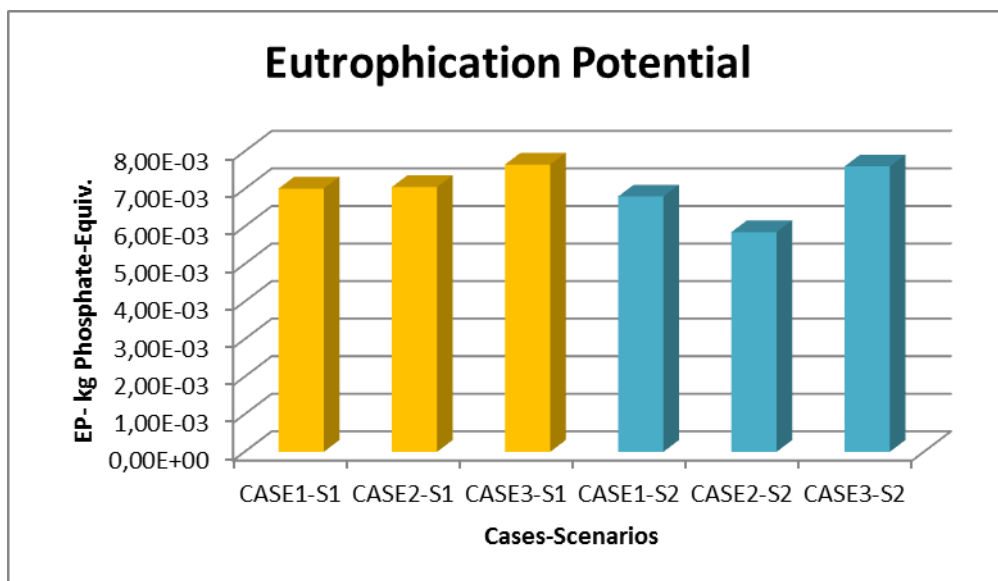


Figure 4.81 Comparison the results of eutrophication potential effects

Unlike other environmental effects, the Case 2 for Scenario 2 is more environmentally friendly application for the Eutrophication Potential (EP) point of view (Figure 4.81). However, in general all options have almost the same EP effects which changes between 5,85E-03 and 7,65E-03.

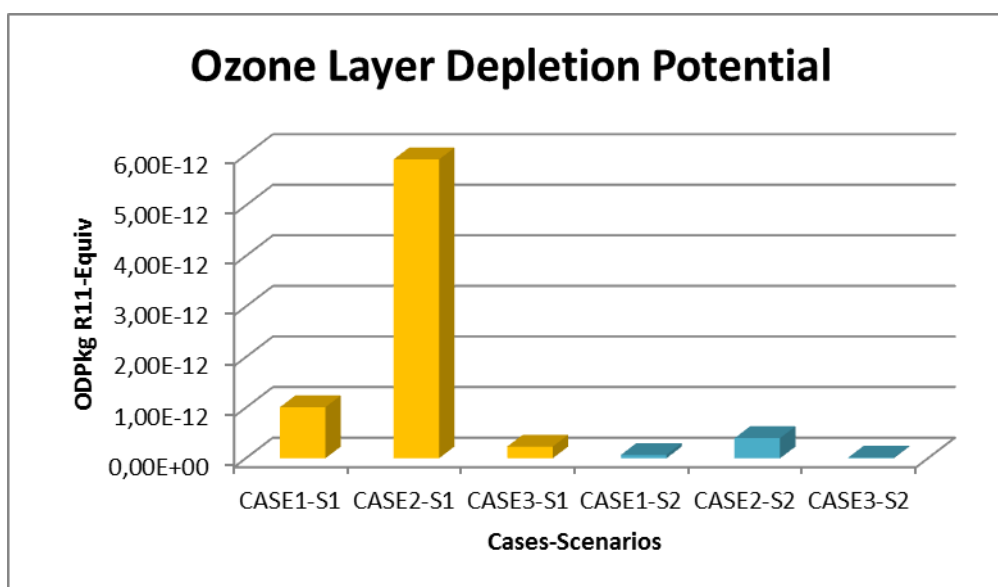


Figure 4.82 Comparison the results of ozone layer depletion potential effects

Ozone layer depletion potentials (ODP) of all options are given in Figure 4.82. According to results it was found that, electric grid mix usage and CF+UF

combination has more impact on ODP. Scenario 2 and Case1-3 has the smallest effect on ODP.

The highest abiotic depletion elements effects was determined for Case 2 (CF+UF) - Scenario 1 (electric-grid mix). For both energy sources CF+UF combination has higher effects comparing to other applications (Figure 4.83).

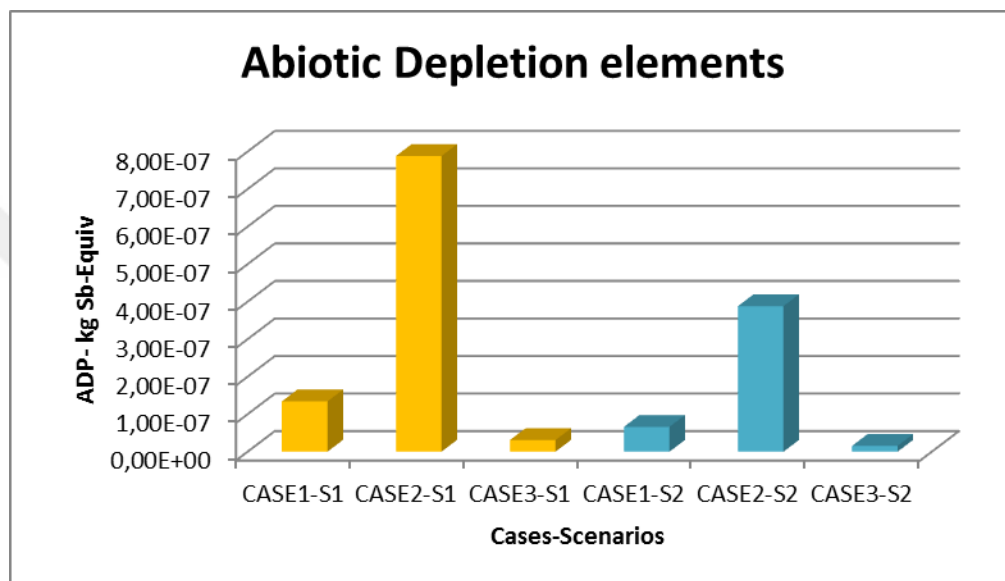


Figure 4.83 Comparison the results of abiotic depletion potential-elements effects

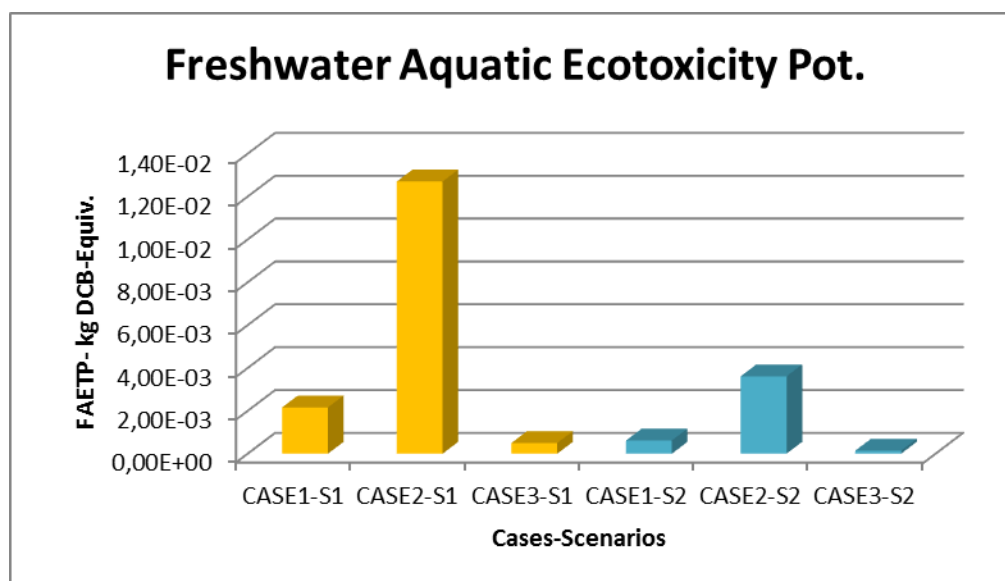


Figure 4.84 Comparison the results of freshwater aquatic ecotoxicity potential effects

Case 2 has the highest effects on freshwater aquatic ecotoxicity especially when the energy source is an electric grid mix (Figure 4.84). This result might have caused from either energy providing activity values of the GaBi Database calculation or reuse water discharge quality. Similar explanation applies to all charts as well.

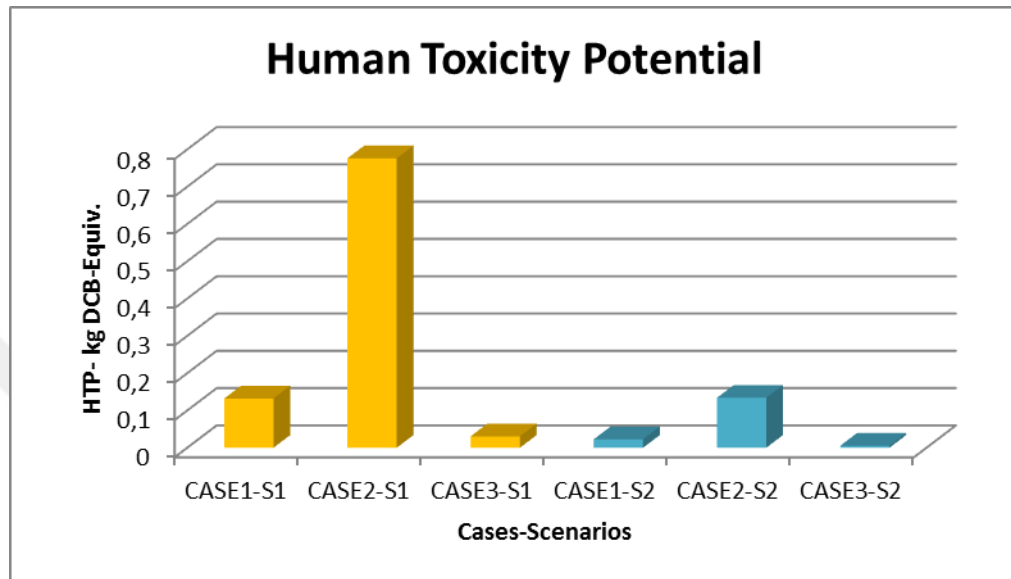


Figure 4.85 Comparison the results of human toxicity potential effects

Human toxicity potential depending on pollution to air, water, and soil is heavily affected from energy source selection. The results for Case 1 – Scenario 1 compared one of the previous study (Tangsubkul-Parameshwaran et al., 2006). Calculation carried out for the same functional unit to make comparisons. The article is about MF with different energy sources and one of these sources is hydro-power energy. The result of the article has closed, but lower value than this study. The reason for lower value is an energy source factor which had chosen electrical grid mix for Turkey in this thesis scope. Electrical grid mix for Turkey obtains its power from both hydro-power and mostly from coal. Since hydro-power is a cleaner methodology than coal. We had expected the result of this study would be a higher than article, which it is. The study result is consist for GWP, POCP, EP, HTP, TETP. Unfortunately, there is no energy source indication in other articles about UF and UV therefore the comparison about UF and UV will be based on cases without scenarios (without energy source).

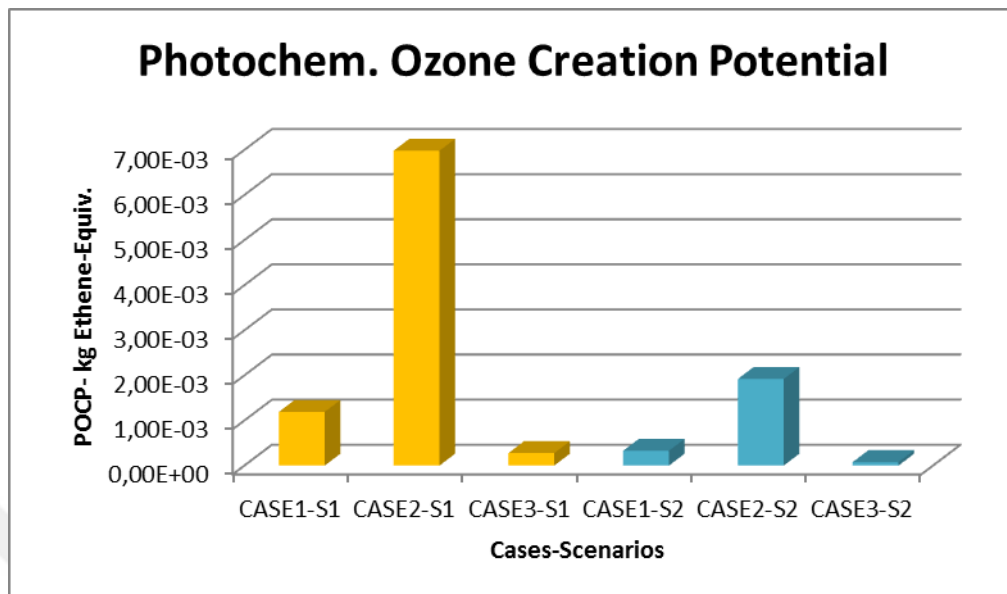


Figure 4.86 Comparison the results of photochemical ozone creation potential effects

POCP reacts to energy source selection and reuse application chose at the same time. Case 2- Scenario 1 has a drastic effect on POCP. Hence Case2-S1 has more effects on the environment relatively also has more effects to the POCP.

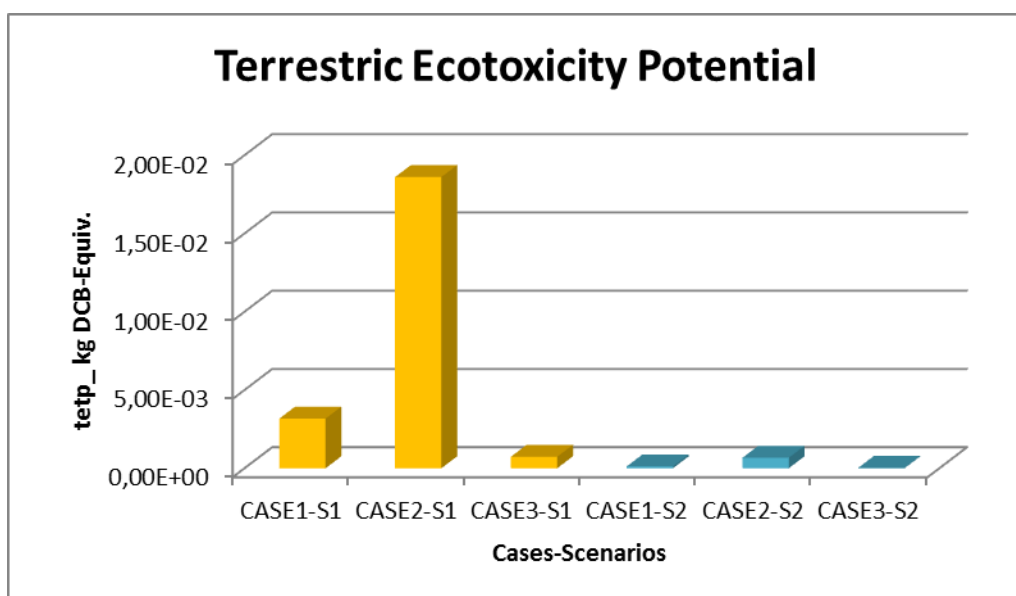


Figure 4.87 Comparison the results of terrestrial ecotoxicity potential effects

Case 2- Scenario 1 has also a significant effect on TETP which means TETP must have been also affected by energy source selection and reuse application as well. TETP is all about exposure, which increase when pollution increase such as CASE2-S1 the most polluted scenario among all.

The results for Case 2 compared one of the previous (Igos-Dalle et al., 2014) Calculation carried out for the same functional unit to make comparisons. The article is about UF and other treatment processes for the three different impact category. The article result is between the range of Case 2 Scenario 1 and 2 values. The average values of Scenario 1 and 2 in the thesis are close to article values. The article result is only for HTP, FAETP, TEP.

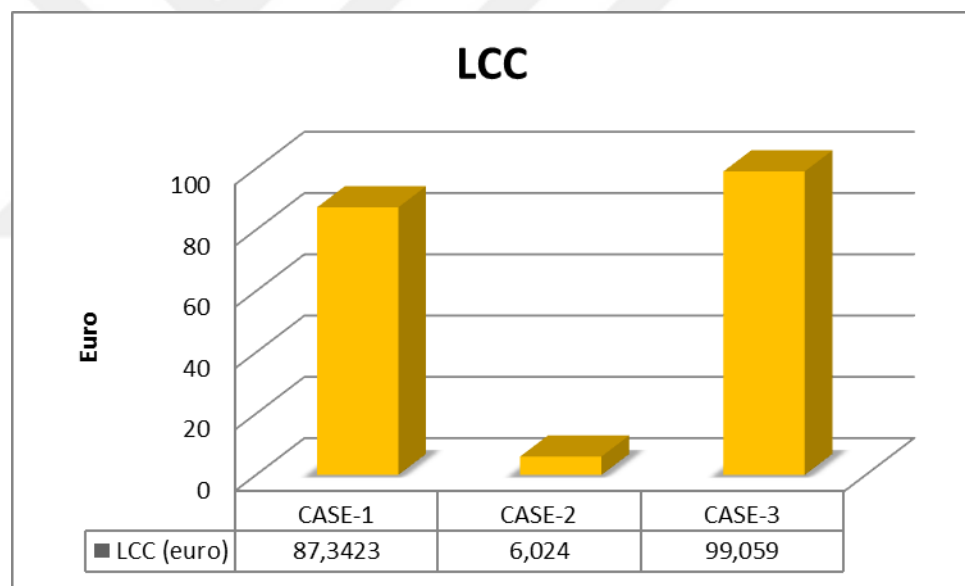


Figure 4.88 LCC results of Scenario 1

In addition to determination of environmental effects of generated reclamation alternatives, life cycle cost (LCC) was also calculated for the Scenario 1 (electric grid mix energy source). The results are given in Figure 4.88. Case 3 (UV) has the most expensive outcome due to the defect of lamp damage issue. The result includes initial cost, maintenance cost and operation cost. Initial cost is the main cost for UV disinfection and makes UV expensive because the lamp of UV what make this cost

higher and due to the lamp replacement need cost result is higher than membrane technology.

This expense also affects the Case 1 which is used UV treatment addition to the microfiltration treatment. Case 2 (CF+UF) is the cheapest treatment. Despite the cleaning activities membrane technologies has the cheapest solution when it comes to treatment alternatives which are investigated in this study.



CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The goal of LCA is to compare the full range of environmental effects assignable to products and services by quantifying all inputs and outputs of material flows and assessing how these material flows have an impact on the environment. This information is used to many alternatives of reuse applications as well as very detailed cost of this application has compared via LCA. Several conclusions have been made, these conclusions may have seen bellow:

1. Energy providing activities has such a huge effect on the environment when they compared to reuse application it's almost fair the say reuse application effect on the environment can be defined as their energy usage of reuse application; except Eutrophication Potential which is relayed mostly upon nitrogen and phosphorus compounds in the water. Therefore, EP could be used to evaluate the efficiency of the water treatment methodology. The most efficient treatment is Case 2 (CF+UF) -Scenario 2 Natural Gas.
2. Case 2 (CF+UF) - Scenario 1 electric-grid mix has the biggest impact on the environment almost all impact categories. The reason for this result mostly have caused by the high pressure need of UF which is led to high energy usage and the electric grid mix certainly has a great influence over the environment.
3. Case 3 (UV) - Scenario 2 Natural Gas has the minimum impact to the most impact categories. Because Natural Gas is known as cleaner energy than the electric grid mix which is mostly obtained from coal in Turkey. Also UV has a less energy consumption then other membrane technology.
4. Regarding to LCC calculations: In general the most environmentally friendly solution is the most expensive one which is Case 3 –UV treatment. Due to the need of lamp damage and requirement of replacement.

5.2 Recommendations

Both LCA and LCC is a compelling tool to determine the most suitable and feasible wastewater treatment alternatives. The scope of this study is compared the more than one scenario and more importantly observed of membrane technology's impact to the environment. LCA calculation heavily depends on functional unit and the system boundaries. Since the functional unit of this study 1 m³ treated wastewater, the result of the study can be multiplied with any Wastewater Treatment Facilities flowrate to calculate the total impact. This study might be developed more with the help of extending the system boundaries further.

In this study, the LCA studies were carried out via the GaBi 6.1 Software and CML 2001 (Institute of Environmental Sciences, Leiden University) impact assessment methodology to determine the environmental impact. The GaBi Database is extensive as it is; unfortunately mainly focuses on industrial process and flows which is used for material transfer. There is such a detailed calculation in The GaBi Database for the industrial process though it's failing to include most of the water treatment technology and environmental process. It is humbly suggested that further additions regarding to environmental process also must be added to The GaBi Database to improve the GaBi Software.

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