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Selection of sustainability indicators through an iterative Life Cycle Analysis procedure for the Zaragoza Urban Water System

Elena Benedi

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by
Elena Benedi

Supervisors
Dr. N.P. van der Steen, PhD, MSc (UNESCO-IHE, Delft)
Prof. Piet Lens (UNESCO-IHE), Chairman

Examination committee
Prof. Piet Lens (UNESCO-IHE), Chairman
P. N. van der Steen, PhD, MSc (UNESCO-IHE)
Prof. Rae Mackay, Earth Sciences (University of Birmingham, U.K)

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The findings, interpretations and conclusions expressed in this study do neither necessarily reflect the views of the UNESCO-IHE Institute for Water Education, nor of the individual members of the MSc committee, nor of their respective employers.

Thesis Dedication:

Papi Benedi for believing in me

Simon Conesa for much moral and technical support

Luca Benedi for giving me renewed energy

Abstract

The challenge of sustainability for the urban water system is considerable, because it faces multiple pressures from natural, social, and economic aspects. The design of sustainability strategies relies on the use of appropriate indicators. In the present study, indicators have been used to assess the sustainability of Zaragoza (Spain) Urban Water System.

An iterative procedure is a method for Environmental Sustainability Indicators selection that follows a series of steps, which ensure that the process is scientifically and socially accepted. In this study, the iterative procedure combines the results obtained from the Life Cycle Analysis (LCA) for scientific support, along with a participative approach by expert stakeholders.

SimaPro (System for Integrated Environmental Assessment of Products) is a software commonly used for conducting LCA. For the present application the results of SimaPro do successfully quantify indicators such as energy, chemical inputs, pollutant discharges, and environmental impact.

The Zaragoza System fits under the type of conventional, large-scale urban system typical of an industrialized city. The assessment of the system revealed major impacts from Wastewater Treatment Plants based on the discharge of heavy metal pollution to the soil. WWTP energy consumption represented the second impact mainly in the form of fossil fuels and climate change. Finally, the management of biosolids as land application, or waste contributed as a significant impact to the pollutant loads. On the other hand proper management of biosolids as cogeneration source had a positive environmental contribution through the reduction of fossil fuels. The use of renewable energies also has a positive contribution to the sustainability of a system.

In the final development of criteria, grouping of indicators into categories within the water field proved effective for narrowing down the selection presented in a questionnaire. Public perception & knowledge were taken into account in the selection of indicators through questionnaires. Further steps included merging of indicators, and followed by the integration through the “Emerging Paradigm”.

Keywords:

Life Cycle Analysis, Urban Water Systems, Environmental Sustainability Indicators, Bellagio Principles, Iterative Procedure, SimaPro Modeling, Eco-points, Questionnaires, Participatory Approach , Emerging Paradigm.

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1. Introduction

Modern urban water systems in the industrialized world were originally designed with the purpose of providing reliable water and proper sanitation services to protect the health of the population. Further developments of the systems targeted to increase efficiency, as well as minimizing costs; as these developments are being achieved a new concern has been raised: are these systems environmentally viable? The transition towards integrating all the above aspects into the Urban Water System calls for the concept of sustainability to be factored in as part of the equation (Lundin and Morrison, 2002).

Sustainability implies that the use of a renewable resource, in this case water, shall not exceed its rate of renewal, while fundamental and ecological processes and structures are maintained (Rijsberman and van de Ven, 2000). The first International meeting that ended with a common agreement towards sustainability took place in Rio de Janeiro in 1992. It was at this meeting that the concept of Agenda 21 was born; this agenda defines the actions that are necessary to address global environmental and social development problems (Bolia, K). The basis of sustainability in the Agenda 21 comes from the concept of integration of economical, social and environmental aspects. This is related to the fact that urban development is driven by the complex sum of these sometimes contradicting forces. It is, therefore, of the utmost importance to understand the interplay between these forces, in order to optimize the systems.

In the concept of water sustainability four key elements are looked at:

- Present water requirements.
- Future projected requirements based on population and urban growth.
- Carrying capacity of the natural system both in terms of quantity and quality of the water source.
- Preserving or improving the operational integrity of the urban system (drinking water, wastewater treatment, waste treatment, and energy consumption) considered as a whole.

The challenge of sustainability for the urban water system is considerable, because it faces multiple pressures from natural, social, and economic aspects. Some of the pressure drivers for Urban Water System include population growth, urbanization, climate change, resource depletion, and lack of funding, amongst others. For instance, water scarcity is a current issue in many cities due to population growth, leading to conflicts between users. Additionally, cities are facing the increasing maintenance and expansion costs of their existing and future systems. Furthermore, another factor that will further aggravate the sustainability of the Urban Water Systems (UWS) is climate change. This

controversial phenomenon has the potential to affect precipitation patterns, increasing the risk of both floods and droughts (Guio Torres et al, 2007). This reality is forcing cities desiring for sustainability, to create flexible and robust strategies that will help them overcome the challenges of the future.

The design of sustainability strategies relies on the use of appropriate indicators. Such indicators shall address the pressure drivers of the system. Indicators provide information about the characteristics and/or condition of a system with an underlying recognizable pattern. This information should be used to unveil the current trends and to predict future conditions. In the present study, indicators have been used to assess the sustainability of Zaragoza (Spain) Urban Water System.

A Life Cycle Analysis (LCA) is a method designed to deal with the proccess of selecting Environmental Sustainability Indicators. More particularly, an LCA will set the basis for the scientific (quantitative) development of ESIs. The quantitative process is the first step towards the development of a holistic management strategy for an Urban Water System.

Currently, there are many on-going efforts in order to select a consistent set of sustainability indicators that may be used by cities. In this research, the strategic selection of sustainability indicators will help Zaragoza to determine whether it is progressing towards a sustainable future or not.

The traditional focus of the UWS has been solely on a technical and engineering basis comprising drinking water treatment, distribution, and wastewater treatment. As previously discussed, such a focus has recently evolved based on the Bellagio Principles and other related concepts to include sustainability in terms of economic, societal, technical and environmental aspects.

One important aspect to consider towards sustainability is the dynamic nature of the Urban Water System. This system shall remain flexible to unforeseen external factors such as droughts, floods, and scarcity. Furthermore, the economic sustainability of the system shall be considered in terms of both cost recovery, and cost effectiveness.

One often neglected aspect contributing to the long-term sustainability of a system is the concept of consensus building amongst the different stakeholders. For instance, public consumption is more moderate when public participation is active. This is due to this fact that the results of applying a fair participatory role in the decision making process will ensure both the sustainability of institutional development, as well as that of the overall Urban Water System.

Finally, environmental sustainability is an essential criterion towards the overall sustainability rating of an UWS. Resource use reduction and recycling of

waste are two prime examples towards environmental sustainability.

While the elements that comprise a healthy Urban Water System are clear, there is no common, clear-cut method to come up with the selection of the best strategy to accomplish all of the above criteria. The steps towards the design of a method for selecting a strategy are as follows;

- Quantify and assess current conditions of the UWS.
- Determine a series of multiple solutions from the assessment.
- List priorities for the system based on criteria for a healthy urban system.

The SWITCH project (Sustainable Water Management Improves Tomorrows City's Health), based in The Netherlands, attempts to assess sustainability of Urban Water Systems in several pilot SWITCH cities. This project is underway to improve and further develop a support system based on the selection of sustainability indicators.

Related to this, the city of Zaragoza (Spain), has set its aim towards becoming a sustainable city by becoming a SWITCH pilot city. Currently implemented by the Agenda 21 Local office and in cooperation with SWITCH, the city is in the process of developing and implementing several strategic activities to improve the sustainability of their Urban Water System management.

In April 2007, a preliminary study was conducted to assess the environmental performance of the Zaragoza Urban Water System. This study will serve as the baseline for further assessments towards creating a set of Environmental Sustainability Indicators (ESI) to monitor the progress of Zaragoza towards sustainability (Penagos, 2007).

Steps to better assess the sustainability progress are;

- Develop a vision statement.
- Conduct further data collection.
- Analyze data via the creation of a model.
- Gather data on sustainability indicators.
- Select most adequate indicators.
- Create several adequate scenarios and strategies.
- Select the most appropriate strategy.

2. Goal and Scope Definition

a. Goal of Research

The goal of this study is to develop an iterative procedure for the selection of indicators for the Zaragoza Urban Water System. These indicators shall support future development of a global ESI strategy with flexibility to be adaptable to any particular SWITCH city.

b. Scope and Activities of Research

1) To further develop the preliminary LCA for Zaragoza by using the SimaPro modeling technique

2) To assess the most important and relevant aspects of sustainable development in Zaragoza with the result of the SimaPro model

3) To quantify some ESIs for Zaragoza with the Eco-point 99 technique.

4) To define a Sustainability Vision and Environmental Sustainability Objectives specific to the city of Zaragoza

5) To undertake an assessment of existing indicators in Zaragoza based on research of existing information

6) To identify different sectors/participating groups involved in the ZUWS management, with the purpose of implementing participative process in future decision making

7) To formulate criteria for the development of sustainability indicators on a consensus based on a Water Commission participation and scientifically driven basis with the SimaPro model

8) To create site specific Environmental Sustainability Indicators for Zaragoza

9) To compare the LCA Zaragoza model to other working case studies for validation of the model (for instance SWITCH–Alexandria)

10) To create opportunity for future development of a global set of ESIs with flexibility to be adaptable to a particular city

3. Materials & Methods

a. Study Site

Zaragoza is located in the northeast of Spain, in the autonomous region of Aragon. It is a fairly compact city, with a population of 700.000 inhabitants, most of which live in apartment complexes. The region of Zaragoza is of semi-arid climate, due to a low yearly precipitation of only 367 mm. The character of rainfall is of short and intense periods of heavy rainfall, which greatly increases the danger of water erosion in the already barren areas, as well as the chance for flash floods. It is of particular importance to note that many surrounding areas in Zaragoza, particularly the Monegros region, are deserts, while many of the valleys are green due to the irrigation practices in the area. The main water users within the Zaragoza UWS include agricultural irrigation, hydropower generation, and urban and industrial supply in their respective order. Water, however is the main limiting factor for cultivation around the surrounding areas of Zaragoza, and due to the sparsely vegetated area, agricultural systems are very fragile.

While Zaragoza receives very low amounts of water via precipitation, it counts with the Ebro river as its main source of water. The Ebro runs in a north to south direction, being born in the Cantabrian Mountains, passing through Zaragoza and discharging into the Mediterranean Sea. 910 km in length and covering a surface of 83.093 km^2, Ebro's hydrological extension is the longest in Spain. Two Ebro tributaries, the Huerva, and the Gallego are also in Zaragoza.

Zaragoza's Urban Water System is modern and well suited to cover all current needs with respect to the drinking and wastewater treatment purposes of all users (domestic, industrial, agricultural, and public). The Zaragoza UWS is moreover, progressively integrating activities to improve its sustainability. On the other hand, Zaragoza also deals with some major pressure drivers that may prevent the system from succeeding in its quest for sustainability. The sustainability actions, as well as the **pressure drivers** are identified below.

As a common scenario in many cities around the world, both steadily growing urban populations and rising environmental awareness (climate and global changes) are increasing the pressure to evolve Urban Water Systems towards sustainability (Palme and Tilman, 2007). The Major of Zaragoza, Mr. Juan Alberto Belloch stated that the population for the city of Zaragoza would reach almost one million by the year 2020. If measures were not taking to account for this, rapid **population growth** and urbanization may result in water scarcity and significant environmental impacts. An unplanned strategy for Zaragoza would put this city further from its objective to become an example for sustainability.

Zaragoza is the fifth largest city in Spain with 700,000 inhabitants and it is projected to continue its growth trend due to factors such as the increase of immigrant population, which currently accounts for almost ten percent of Spain's population. Specifically, in Zaragoza's demographics publication, it is stated that since the year 2000 immigrant population has incremented by a staggering 900%. A precise growth forecast is therefore very difficult to obtain, and as stated later in this study, the projected expansion of the UWS may not be sufficient to cope with this growth in domestic demand *ceteris paribus*.

Moreover, Zaragoza also has a projected **growth in urbanization** due to factors aside from the above mentioned population increase. Several large-scale developments are to take place within the next decade in the surrounding areas of Zaragoza. Projected by the year 2015, the Gran Scala will become Europe's largest casino complex. Consisting of 32 casinos, 70 hotels, 232 restaurants and 500 shops, this project hopes to attract 25 million visitors a year. Such estimates for rapid increases in population will undoubtedly affect the water supply, and services provision of the Zaragoza Urban Water System.

A second project affecting the urban development is the Logistics Center of Zaragoza, also known as PLAZA project. This development will become the largest logistics center in Europe, with an extension of 12.826.898 m^2. Zaragoza has been chosen due to its critical location in the southeast of Europe and based on its complete transportation system of trains, roads and airports connecting it to some of the major centers of consumption and production. The development of a commercial center of this scope will also undoubtedly affect Zaragoza's water supply and services provision.

A third pressure driver in the Zaragoza Urban Water System is the **climate change**. Recently, a scientific study was conducted to assess the environmental changes affecting the Pyrenees Rivers due to climate change. This study revealed that in the last fifty years, the river's flows have steadily declined loosing 30% of their original flows. For example, the Aragon River from the Yesa hydrological region, expected to supply Zaragoza's Urban Water System in the near future, has reduced its 1950's flow of 1200 Hm^3, to 800 Hm^3

by the year 2000, i.e. a 25% reduction in flow. A second method being used to demonstrate the reduction in available water is through the significant reduction in the snow layer and the periods of the year that snow is present.

Additional studies were developed to project the precipitation and temperature patterns of the Pyrenees regions, which supply water to Zaragoza. The results of this study demonstrated a significant reduction in precipitations. Additionally, the increase in temperatures will significantly reduce the amount of rainwater collected, due to an increase in evapo-transpiration. In exact figures, it is determined that the amounts of available water will be reduced between 300-400 liters per person per year. The conclusions of this study stated that the current water availability feeding the distribution system is at its limit, and future projections need to be addressed.

To counteract for these pressure drivers, Zaragoza is preparing itself for an increase in water demand by demonstrating a desire to plan ahead and to become a sustainable city in the future. Some of the different activities that demonstrate this desire towards becoming sustainable include;

- In 1993 a WWTP providing tertiary treatment was built (Penagos, 2006)
- In 1994 EBROPOLIS was created, this is, the Association for the Strategic Development of Zaragoza. Its objective is to design strategies for the future of Zaragoza by 2010. This was the seed for the Agenda 21 local.
- In 2000, Zaragoza City Council decided the implementation of 10 sustainability indicators for the city of Zaragoza. These indicators were previously proposed by the European Environmental Agency.
- Also in the year 2000, the City Hall of Zaragoza did abide by the "Letter of European cities towards sustainability" (Carta Aalborg).
- In July 27th 2001 Zaragoza City Hall approved the local Agenda 21. This document describes the plan of action rendered up to date, as well as the implementation of sustainability indicators. One of its main purposes is to incorporate citizen's participation for the design of a collective city for the future. By definition Agenda 21 is the foundation of a sustainable development, integrating environmental aspects along with the policy regulations. Here, integral focus is the key to sustainable development
- While historically, the increases in population had seen a parallel growth in the water consumption, the historical maximum of urban water consumption took place in 1979, with 106,4 Hm^3. Since then, even though population has increased by 25.000 inhabitants, the total

consumption has been progressively reduced. Some of the activities responsible for the reduction in consumption include;

- Substitution of irrigation in public gardens with groundwater, instead of water from the network.

- In 2002, a new plant for sludge treatment at Casablanca treatment station was started. It is estimated that the sludge treatment was able to recover 5,26 Hm^3 of drinking water in the year 2003.

- The campaign "Zaragoza, water saving city" worked along the introduction of water saving habits by information dissemination and by increasing social awareness, as much as the installation of water saving devices (W.C flushing systems, washing machines, etc). This has achieved an annual reduction in domestic consumption of 5.6% over the last ten years. The new proposed goal is to reduce water consumption from the current average consumption of 104 liters per person per day, to 90 liters per person per day by the year 2010

- Improvements in the piping system and pipe joints in the distribution networks have considerably reduced water losses.

- Reduction and recycling of water in a closed circuit in highly water-consuming industries in the city of Zaragoza.

- The Zaragoza Municipality has developed a fair water tariff for affordability and cost recovery purposes. This tariff is also established to reward water saving behavior.

o Development of the World Water International Exposition, 2008. The slogan of this exposition is "Water and Sustainable Development".

Zaragoza Summarized in Facts:

Population	**700,000**
Precipitation	**367mm/year**
Main River	**Ebro**
Discharge Load of Ebro	**19,000 M m^3**
Total Water Consumption in 2007	**64 Hm^3**
Consumption per person per day	**110 l**

b. General Conditions of the Urban Water System

Zaragoza, extracts the drinking water to supply the urban system out of the Canal Imperial de Aragon, from the province of Navarra. This water supply will change soon, once the new works from the Yesa Reservoir (Pyrenees) have reached its water capacity within the next year, and the water rigths commissioning is completed. This water is mainly transported by gravity to the Casablanca Drinking Water Treatment Plant. The drinking water plant of Casablanca treats the water for the whole city of Zaragoza. It has a capacity of 6 m^3/second, almost double the average consumption of the city. Once the water has gone through the treatment process, it is put into water deposits located on-site at Casablanca. This stored water will be later distributed to the urban system users including domestic, industrial, and public uses. Water for agriculture is mainly obtained from groundwater sources.

An important element found in the Zaragoza distribution system to domestic users is the presence of Aljibes (Breaking pressure tanks) at many residential buildings. There are around 7,500 of them in the city, and they pose several problems to the UWS sustainability. These will be discussed later.

After consumption, wastewater is collected in a combined sewage system which collects both domestic, partially treated industrial wastewater, and untreated storm water. Collected storm water is low due to the characteristic low precipitation patterns of the region. Wastewater is then diverged to two different wastewater treatment plants, Cartuja and Almozara, built in 1983 and 1989 respectively. Cartuja, the larger plant, can serve a population of 1.200.000 equivalents with a treatment capacity of 259.200 m^3 per day. Almozara serves a population of 100.000 equivalents with a discharge capacity of 34.560 m^3 per day. The receiving body for the treated waters is the Ebro River. At the end of its course, Ebro River discharges into the Mediterranean Sea.

Industrial discharges are also diverted to the treatment plants. Industries are subjected to ISO standard monitoring programs to measure pollutant parameters prior to their discharge to the treatment plants, or directly to the receiving water body.

Sludge waste management is carried out differently at Cartuja and Almozara; Cartuja treats sludge waste via incineration. Its ovens have a system to filter the combustion emissions resulting from the process. The ovens co-generate part of the heat extracted from incineration, and recycle it for the further drying of the sludge, as well as to produce electricity for a vapor turbine of this system. On the other hand, Almozara deals with sludge via a two-step digestion. The biogas produced from the digestion is stored for cogeneration of 75% of the energy consumption of the plant.

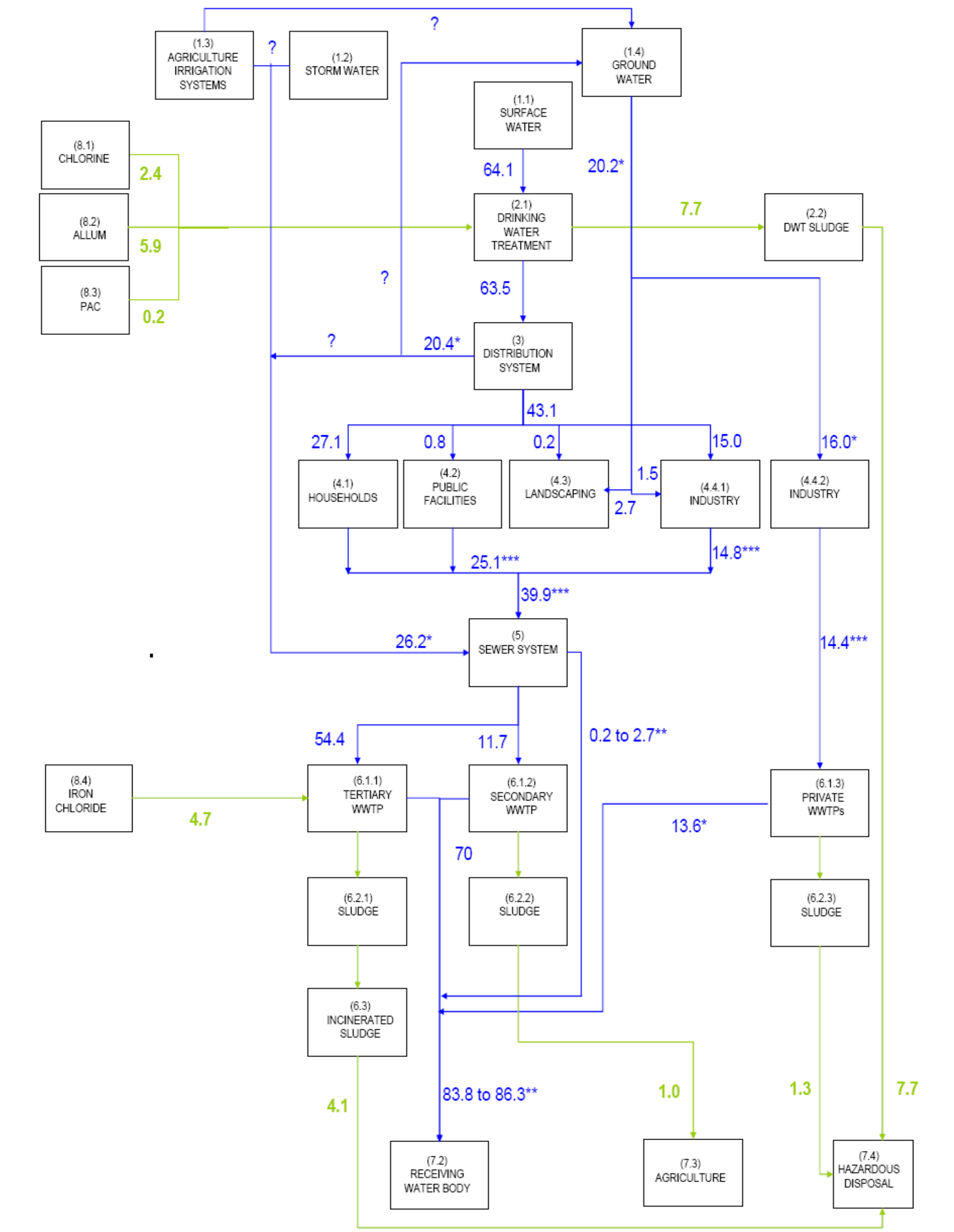


Figure 2. Flow Diagram for Zaragoza UWS. Lines and numbers in blue stand for water flows (units are million m^3 per year). Chemical products as well as sludge flows are represented by lines and numbers in green (units are thousand tons per year). Data used for this diagram are from the year 2006.

* Values that have not been measured but estimated
** Storm water overflows were estimated for the period 2001 – 2006 and are completely different between years. Therefore an average value is not given, but rather a range.
*** 90% of water use is assumed to go to the wastewater system
? Indicates balances that could not be completed due to information gaps
Values that have been actually measured are not given any mark in this figure

Fig. 1 Flow Diagram for Zaragoza UWS

Underground water sources

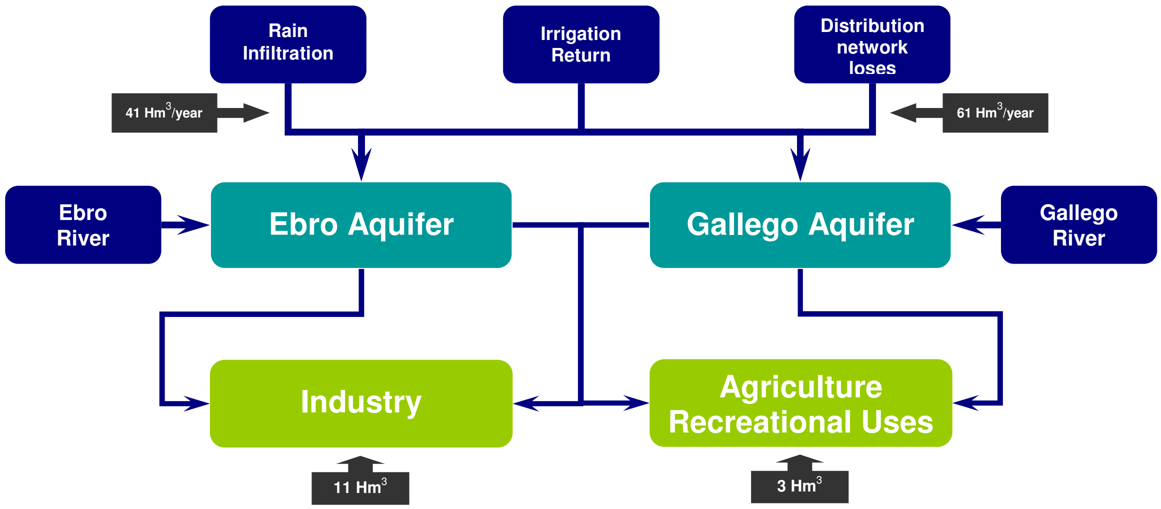


Fig 2. Underground Water Sources

Extraction

The water for consumption for the city of Zaragoza currently comes from the Canal Imperial de Aragon, coming from the Ebro in the province of Navarra. In order to counteract for the large seasonal fluctuations of the Ebro (from highest 500 m^3/sec in March to lowest 30 m^3/sec in August) the water supply for the city is largely regulated by dams upstream.

Due to these seasonal fluctuations, raw water quality is poor. Parameters such as conductivity and hardness increase during the low discharge summer months. On the other hand, peak high discharges during the rainy months (Spring and Fall) induce high amounts of suspended solids and organic matter. Consequently, the low water quality parameters of the current water source lead to an increase in the use of chemicals to reduce such a parameters to regulated standards. The increased used of chemicals contributes to an unsustainable system in terms of environmental, health, and economic cost to the system.

Furthermore, high summer temperatures also increase the presence of human microbial pathogens in potable water. This scenario calls for high chlorine demands leading to hyperchlorination, which increases undesirable disinfection by-products such as Trihalomethanes, Chloroform, and Bromodichloromethane. Unfortunately, such by-products may have harmful health effects on the Zaragoza population.

In the current system, the water in Zaragoza does not meet distribution standards recommended by the European Union in the following parameters;

- Color, turbidity, and temperature.
- Mineral content: sodium, sulphates, calcium, and chlorates.
- Aluminum.
- Organic compounds.

New source of potable water

A new source of better quality water, coming from the Yesa Reservoir at the Pyrenees is estimated to be integrated by 2010. This action is included in the so called "Pact of Water" and it was also included in the Ebro Watershed (CHE Hydrological Plan).

This new source of water will first guarantee a secondary source for the city, along with the improvement in the quality, due to its relatively unpolluted alpine origin from the Yesa reservoir.

This new distribution network has been dimensioned for a maximum demand of 700.000 to 850.000 persons. Such a demand will cover the current Zaragoza population, as well as its future population growth. The new source of water from the Yesa can be qualified as one of the most significant steps that Zaragoza has taken to guarantee that the growth of the metropolitan area occurs in a sustainable manner.

A second benefit towards water sustainability coming from the Yesa source is related to its better quality. Yesa water will require less treatment thus reducing the use of chemicals. This will have a direct, measurable impact in health (social), environmental and economic benefits.

Notwithstanding the above, it is worth noting that this project still presents some problems. The first obstacle can be linked presently inadequate distribution network, incapable to prevent losses of this new quality water.

Currently, there is a delay in the implementation of this project. This is due to the scarcity of precipitations and the consequent low water levels at Yesa Reservoir. It should be noted that, as a requirement by applicable laws, these reservoirs must be at least at 60% of their capacity in order to be utilized.

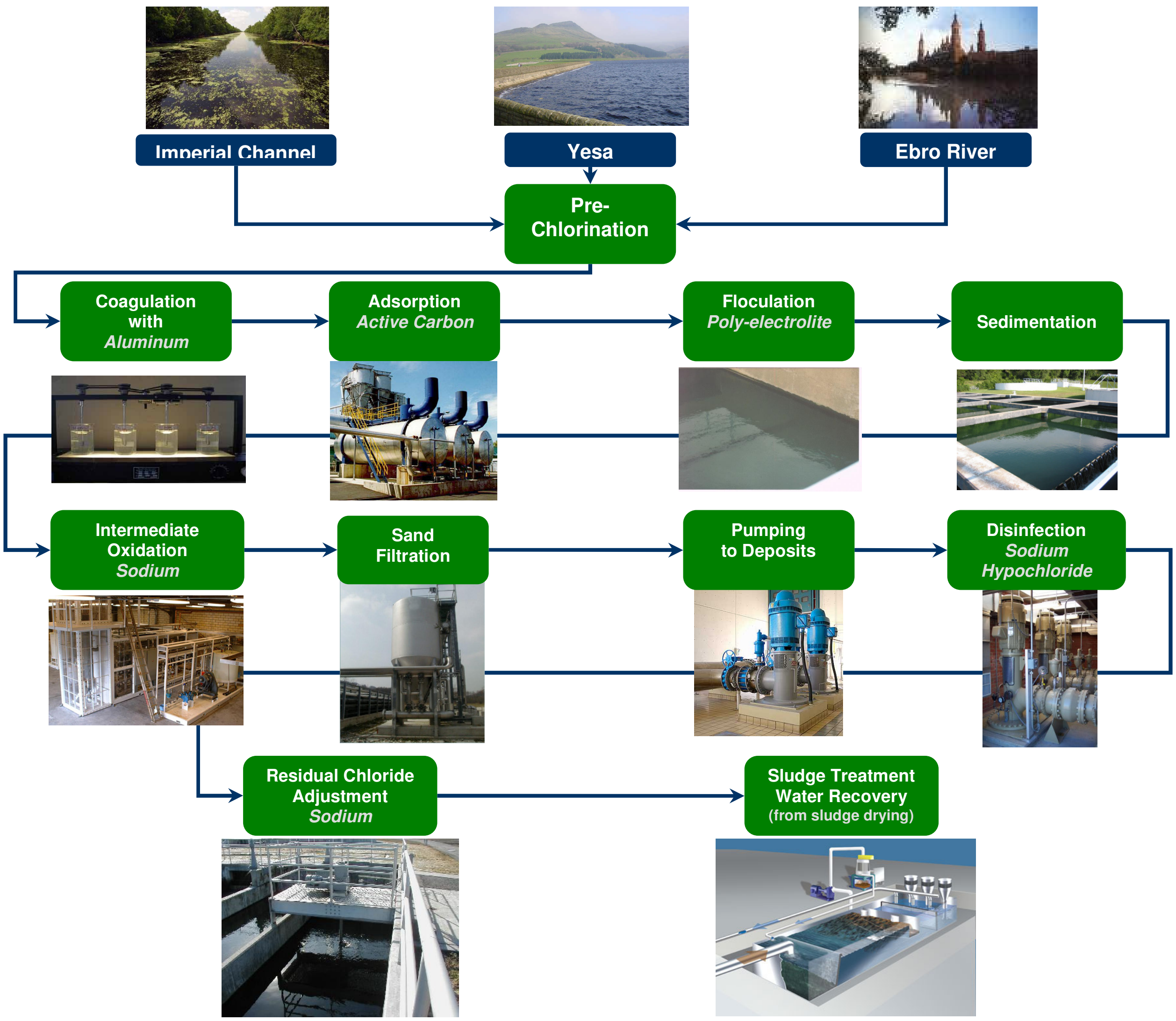


Fig. 3 Casablanca Water Treatment Flow Diagram

Potabilization

The potable water plant of Casablanca treats the water for the whole city of Zaragoza. It has a capacity of 6 m^3/second, almost double the average consumption of the city.

The potabilization stages include;

- Screening
- Oxidation of organic matter through Sodium Hipochlorite
- Separation through coagulation of Aluminum Sulphate
- Sand filtration
- Disinfection with Sodium Hipochlorite

The potable water plant of Casablanca, has a treatment for its sludges. Started in 2003, this sludge treatment allows more water to be recovered during the potabilization process: through the cleaning of filters and purging of water filtered. This new plant has an activated carbon system that allows for better treatment of sludges. This new technology improves the rating towards the sustainability of Zaragoza.

A recent step taken towards making the potabilization proccess more sustainable is the substitution of gas chlorine (1.100 tons) by Sodium Hypocloride (450 tons). Sodium Hipochlorite is a much less harmful substance and that can be used in smaller amounts.

In terms of water losses, the main potable water tanks used for potable water storage previous to distribution are located on-site in the Casablanca potabilization plant itself. These deposits have a capacity of 180.000 m^3 and while they were quite outdated with major leaks, the repairing and renovation of these deposits was completed at the beginning of 2008. Such activity will have a significant sustainability impact in the reduction of water losses.

Distribution Network

In terms of energy consumption, the main distribution network for the ZUWS is gravity fed. Due to this, the energy consumption is merely insignificant.

In terms of water losses, around 50% of the distribution network is over 30 years past its efficiency status. Many pipes currently use fiber cement as a component responsible for a large number of leaks due to its weakness in the structural components. This material is being progressively replaced by pipes of ductile material which are much more flexible and consequently more resistant to leaks.

Currently, the losses in the Zaragoza network are of serious character. In 2003, of the 71,7 Hm^3 treated in the Casablanca plant, only 41,6 (58%) were accounted by the municipalities.

On the other hand, there are several sources of unaccounted for water extraction coming from the following sources;

- Public irrigation.
- Public institutions (firefighters, swimming pools).
- Illegal connections.
- Measurement errors.
- Losses in the distribution deposits (filtration and evaporation).
- Losses in the pressure tanks (Aljibes) belonging to communities (3-5 Hm^3/year).

Delivery of water to many of the housing blocks has efficiency problems due to the 7500 existing breaking pressure tanks (Aljibes). These Aljibes are known to cause the following problems;

- Energy losses due to the pressure breaks.
- High leakage due to lack of maintenance.
- High health risks (Legionella bacteria) due to bottom storage and loss of Chlorine during the time delay in the Aljibes.

The European Union contributed economically to the distribution network of Zaragoza, to create a plan that would reduce the network water losses from the current 25% to a maximum of 15%. At this time the improvement plan is attempting to replace 33 km of pipeline a year up till this year of 2008.

The University Department of Hydrogeology in Zaragoza, attributes some of the distribution problems to the following issues;

- Low velocity.
- Variable pressures depending on topography & the deposits supplied.

The Hydrogeology department proposes a better functioning of the network through a digital system to establish the pipe pressure between 2-6 atm.

Water Tariffs

Currently the water tariffs have two components;

- A fixed charge.
- A variable charge based on the volume of water consumed.

The water tariff applicable to the variable charge is of progressive character: for a higher consumption, there is a greater charge per cubic meter.

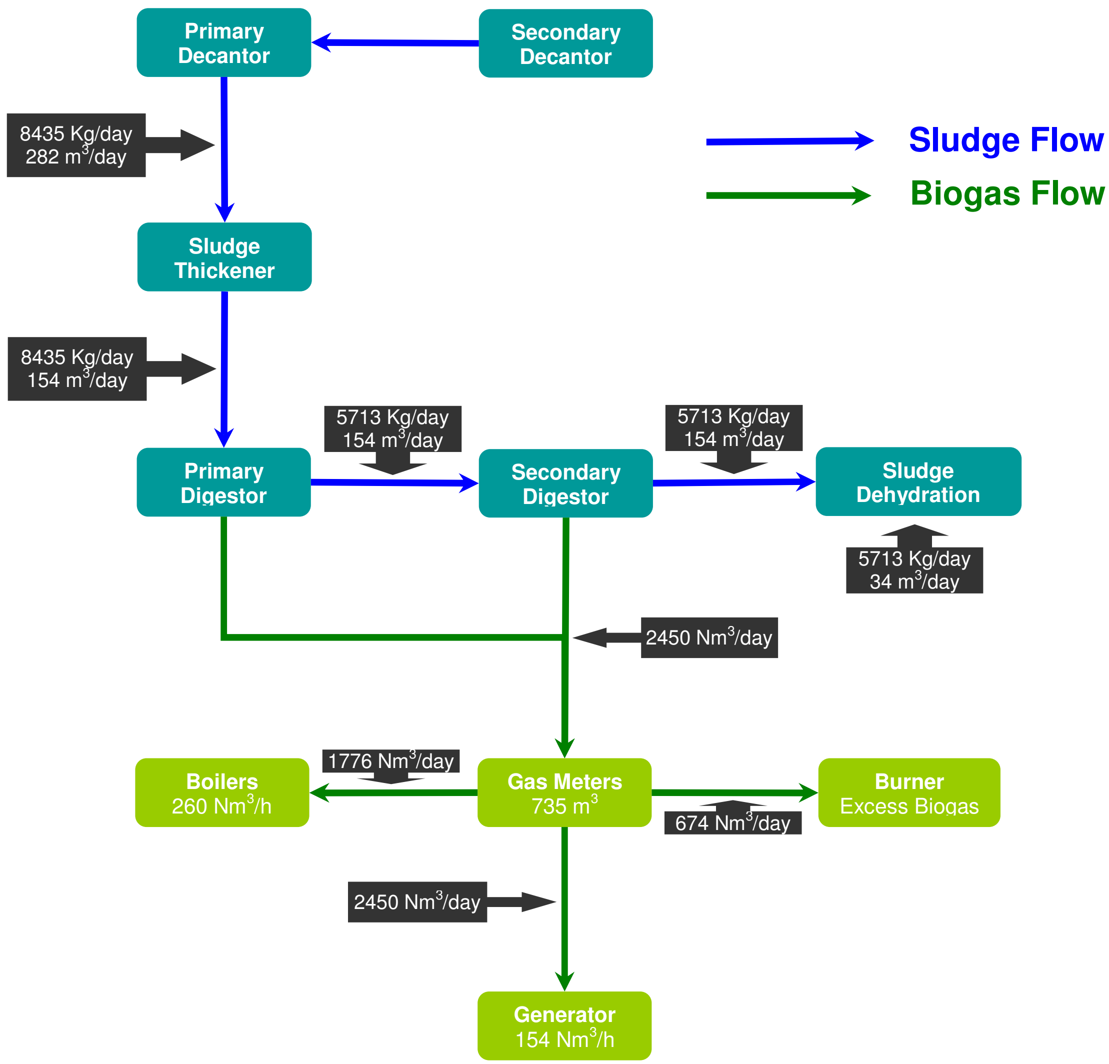
According to the municipal services, renovating all the pipes with the new water source coming from the Pyrenees will increase the price per unit volume of water by 62%. The improvement in the quality of water coming from the Pyrenees will then increase the cost of water to 40 cents/m^3.

Wastewater distribution and Wastewater Treatment

Currently the wastewater distribution network is 923 km in length.

There are two wastewater treatment plants in Zaragoza city; La Cartuja and Almozara

Fig. 4 Cartuja Wastewater Treatment



Cartuja plant treats 85% of the wastewater of the whole city. It currently operates at 62% of its maximum capacity. In the year 2007, Cartuja treated 51 Hm^3 of wastewater

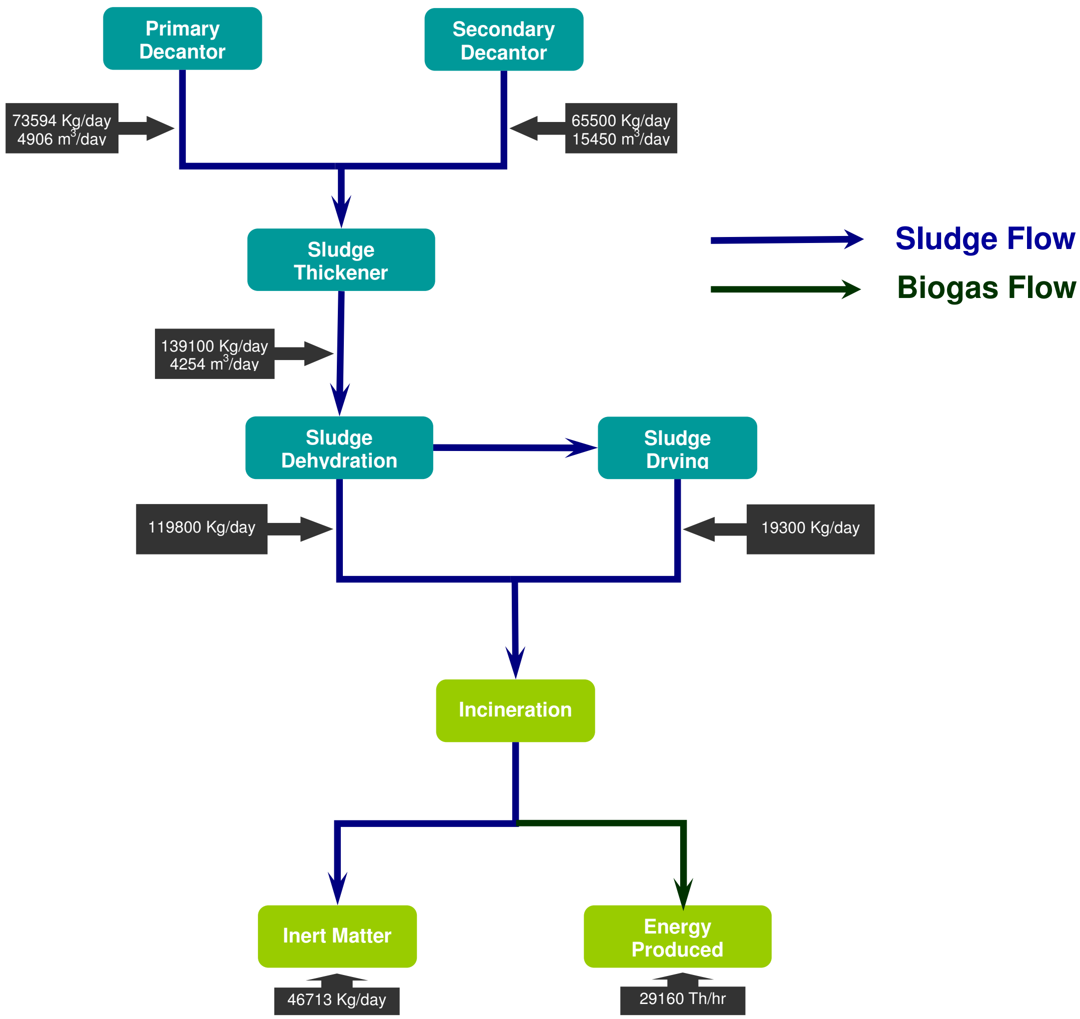


Figure. 5 Almozara Wastewater Treatment Plant

Almozara Wastewater Treatment Plant treats 12 Hm^3 of wastewater and operates at 92% of its maximum capacity.

WWTP	Cartuja	Almozara
Population Capacity Served	1.200.000	100.000
Flow at design (m^3/day)	259.200	34.560
Treatment Processes	Primary Decantation, Activated Sludge, and Secondary Decantation. Phosphorus removal via Iron Chloride	Primary Decantation, Activated Sludge, and Secondary Decantation Disinfection, Deodorization
Sludge Treatment	Sludge thickening, dehydration, incineration,	Sludge thickening, dehydration,
Cogeneration	Heat recovery from incineration to dry up further sludges, maintain combustion, & produce electricity	Biogas recovery from sludge to produce 75% of plant's energy

4. Literature Review

a. Iterative Procedure methodology

An iterative procedure is a method for Environmental Sustainability Indicators selection that follows a series of steps, which ensure that the process is scientifically and socially accepted. In this study, the iterative procedure combines the results obtained from the Life Cycle Analysis (LCA) for scientific support, along with further research of ESI from Case studies, and final identification of Zaragoza specific ESI´s via a participative approach by expert stakeholders. The results obtained have been gathered and a holistic perspective has been applied to come up with the final criteria for the selection of the Environmental Scientific Indicators.

An effective framework accomplishes two important goals: first, it helps to determine priorities in the choice of indicators; and second, it triggers the identification of indicators which may become more important in the future. The steps taken were as follows:

1) Specify overall purpose- to assess the environmental sustainability of the Zaragoza Urban Water System, in order to identify the environmental indicators/criteria for future studies. Additionally, the results of the Zaragoza Urban Water System may be compared in future investigation studies with the Alexandria Urban Water System in order to further improve the selection of environmental indicators at different levels in terms of local (city specific), regional (country specific), and global (international) scale.

2) Define system boundaries- Temporal, spatial and life cycle boundaries are addressed in this study.

Time perspective- Since sustainability implies a long-term approach, temporal scales have been selected accordingly (Lundin, M & Morrison, G., 2002) One decade prior to our studies and one in the future is the most realistic scenario in terms of finding reasonable data for the Zaragoza Urban Water System.

Geographical boundaries- The geographical boundaries for an urban water system are usually limited to include the municipality watersheds (Lundin, M & Morrison, G., 2002). Hence, in our case, the ZUWS is limited to the municipality watershed. However, the limits are questionable based on the agricultural boundaries, because they have a serious impact in the Urban Water System.

Life cycle boundaries- This defines the unit processes included in the system, where the up-stream and down-stream cut-offs are set (Lundin, M & Morrison, G., 2002).

In this study, the ZUWS life cycle boundaries include;

- Water withdrawal from ground & surface sources (Current source: Canal Imperial de Aragon; Future source: Yesa Reservoir
- Drinking water treatment (Casablanca)
- Drinking water transport (include Aljibes energy consumption, pipe replacement, Casablanca water deposit)
- Wastewater treatment (Cartuja & Almozara)
- Discharge of storm and wastewater
- Sludge treatment: incineration and/or disposal.
- Potential agricultural activities within the urban water system.

3) Develop a framework to guide the identification and selection of ESI- These frameworks are commonly extracted from a stress-response model, example OECD, UNCSD. In this study, LCA has been our chosen framework.

4) Selections of ESI- Following the development of the framework, appropriate ESI's have been selected from Case Studies and literature review. It should be noted that a limited but comprehensive set of ESI is required, i.e. as few indicators as possible should be selected to address the most important issues. As previously mentioned, the LCA have been used in this study to identify such aspects.

5) Information Collection- While assessing an urban system, the study should be as retrospective as possible. After information assessment, the ESI can be evaluated against relevance to the sustainability of the specific system, predict potential problem, and quality of information.

6) Evaluate framework- The chosen ESI's are checked for relevance on the UWS, assessing their capacity to monitor the current sustainability of the system, as well as their prediction power for future problems.

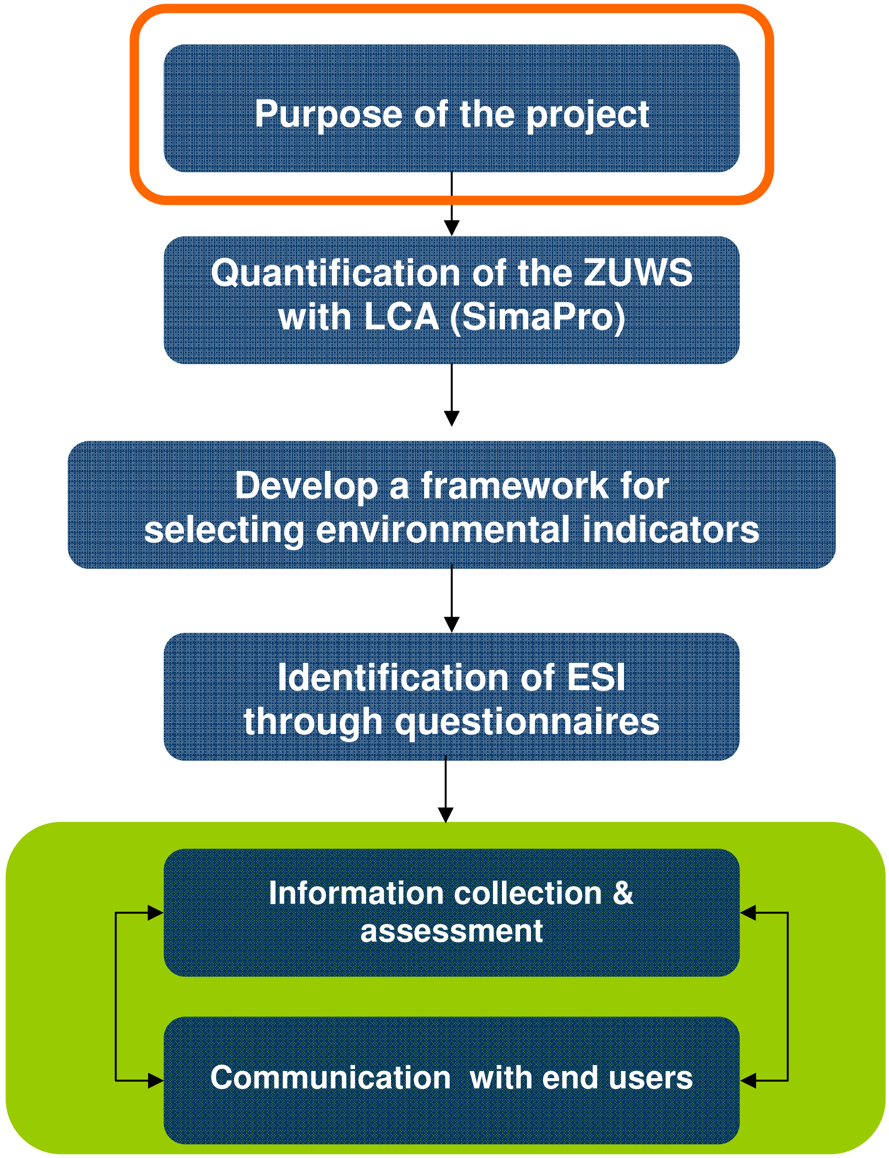


Figure. 6 Developed Iterative Procedure

The iterative procedure has been sketched in the above Figure 6. This illustration depicts the steps taken for the selection of ESI, and how these steps interact with each other in the process until completion.

b. LCA definition

A Life Cycle Analysis (LCA) is a method to deal with the process of selecting sustainability indicators. An LCA works by evaluating, and where possible, reducing the environmental impact for the entire life cycle of a product, service, or process (Lundin, M & Morrison, G; 2002). LCA sets the basis for the scientific (quantitative) development of Environmental Sustainability Indicators.

Advantages of an LCA;

- Well established method.
- Commonly used for strategic decision-making support.
- Includes an impact assessment phase.
- Potential impacts can be quantified.
- Proven track record in rating Urban Water Systems.
- Reveals the importance of nutrient recycling & energy recovery.
- Integrates economic and social costs.

Disadvantages of LCA;

- Complex and time consuming method.
- Overlooks water amounts and losses.

c. LCA methodology

An LCA study requires four steps;

1. **Defining the goal and scope of the study**
   Goal and scope are the guides that ensure there is consistency thorough the LCA process. In this thesis, the goal has been to create a model of the Zaragoza Urban Water System with all its processes and stages from the initial water extraction to the final treated water discharged.

2. **Making a Life Cycle Inventory (LCI)-**
   This involves the data collection of all the environmental inflows and outflows. The inventory entails details on energy, materials, wastes production, and emissions during the life cycle of the product or process.

   Some important criteria to consider when selecting quality data include;

   - <u>Complete</u>- Includes all inputs and outputs of the process or material production (energy, materials, emissions).
   - <u>Scientific</u>- Uses scientific based analysis to obtain and process data.

- Reproducible- Based on the detailed information and methodology, the report is written in such a way that the results are reproducible.

3. Creating a Life Cycle Impact Assessment phase (LCIA)- LCIA is defined as the phase in the LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts, according to the inflows and outflows data acquired. Thus, the first step to be taken is the selection of the most appropriate impact categories, guided by the stated goal of the study. Once these categories have been determined, the LCI results need to be assigned to the impact categories. Then, characterization factors are defined to account for the relative contribution of an LCI to the impact category.

In the goal and scope of this study, the characterization chosen to evaluate the ecological impacts is the Eco-Indicator 99. This is a complex framework, but the results and their meaning are easier to understand and evaluate, giving an advantage to decision makers.

There are a number of optional additional steps that can be taken once the LCIA has been completed, namely:

Normalization-

This is a procedure to unveil the partial contribution of the impact category to the overall environmental problem. This is mathematically done by dividing the impact category indicators by a "Normalization" value. Normalization may be useful for the following reasons:

- To discard those categories that only contribute marginally to the environmental impact, thus reducing the number of categories to be evaluated.
- Normalized results can be used as a guide to compare the order of magnitude of different environmental problems across Europe.

Grouping and ranking

Impact categories may be grouped or ranked, in order to make interpretation easier. Grouping may be based on common features whereas ranking may be based on sorting categories.

Valuation or weighting

Weighting is a procedure to unveil the relative importance of these scores. To do this, the characterization scores are multiplied by a weighted factor for each category.

In this research, the assessment method employed has been the Eco-Indicator 99. This procedure uses "Authoritative panels", where a panel of experts has assigned the weighting factors.

4. Interpretation of the results-

Probably the most practical of the phases in the LCA is the fourth and final phase: interpretation. This phase comprises three steps:

- Identification of issues.
- Evaluation of the results to double check completeness and accuracy of the modeling and data input process.
- Final conclusions & recommendations extracted from the modeling process and the results.

The technique used in this study for LCA is described as follows:

1. First, the purpose of this thesis has been to create a model for the Zaragoza Urban Water System, with all its processes and stages from the initial water extraction to the final treated water discharged. Researchers should be aware that models are always a simplification of reality, and they may become distorted. Hence the need of complementing them with additional information, as done in this study. The result of this process mapping is a **process tree** including all relevant stages.

2. Each process will include all relevant inflows and outflows based on data collected from several sources, but mainly from the Municipality and the Infrastructure departments of the City of Zaragoza.

3. A second phase is the life cycle impact assessment. At this stage a different type of model is used to describe the relevance of inflows and outflows. A series of impact categories are selected based on the type of Eco-Indicator assigned. Impact categories can range from eutrophication, climate change, and health effects. The weight observed on each impact category allows for a better interpretation of the results of the system.

d. How SimaPro works

SimaPro (System for Integrated Environmental Assessment of Products) is a software commonly used for conducting LCA. For the present application the results of SimaPro do successfully quantify indicators such as energy, chemical inputs, pollutant discharges, and environmental impact. However, it also has limitations since it does not account for water quantities. Thus water availability, consumption, and losses are not part of the modeling results.

Construction of the SimaPro Model has been carried out as follows (Mahgoub, 2007);

1. System parameters definition of the goal, scope, unit, boundaries and quality of data. At this time the components/processes within the system were identified including the waste disposal step. The waste processes were merged and in this way the assembled product is the actual LCA.
2. Run of an inventory analysis including data collection, validation and relation of the data. The inventory analysis is based in the inputs/outputs gathered from each process in the LCA. At that time processes were linked together, and the schematic of all processes was obtained.
3. Categorization based on the selection of impact categories; classification of input/output based on previously defined categories; characterization by quantification of the output based on Eco-Indicator 97; and valuation based on Eco-Indicator 97. At this stage impact assessment and prioritization took place.
4. Interpretation and validation of applicability of results, based on the questionnaires filled by the expert's panel.

e. Environmental Sustainability Indicators

Sustainability refers to the degree of sustainability of the Urban Water System maintenance and their applied and projected improvements to the system. Of special notice is that the process of sustainability is continuous and requires not just punctual efforts, but consistent, long-term commitments.

Environmental sustainability is, therefore an essential criterion towards rating the overall sustainability of an UWS. It can be achieved by taking pollution prevention measures for water quality by controlling discharges and hence, reducing nutrients, and consequentially reducing chemical inputs into the system. A second measure towards environmental sustainability involves the precise use of natural resources to ensure the long-term availability of such resources. A final determining aspect towards environmental sustainability entails recycling and reuses methods for inputs such as wastewater and storm-water, and sludge into the UWS.

Indicators are numerical figures, providing information about the characteristics and condition of a system with an underlying recognizable pattern. This information is a tool that can later be applied to foresee future conditions and trends. As such, indicators can be used to develop sustainable strategies for different systems, in our case to measure the Sustainability of Zaragoza Urban Water System.

A current example of an indicator, in the Climate Change impact category, is the percent loss of ice in the Poles due to global warming

Theme	Indicator
Climate Change (Global Warming)	Percentage of ice lost in the Poles

Based on the Bellagio Principles and thesis research of (Lundin et al, 2002), for an indicator to be sustainable it shall compile technical, socio/political and economic aspects within its strategy. In order to achieve their level of effectiveness and efficiency, indicators should be selected according to the following **criteria**;

Clarity- Ability to communicate a complex problem in a clear and concise manner that is accessible to a wide audience.

Support- Indicators shall contribute to the long-term design of strategic actions, while providing short and medium monitoring programs for its implementation. Also, indicators should be capable to address new issues required for future activities and strategies.

Integration- All aspects, economic, social, political and environmental shall be incorporated for complete integration. A special emphasis in human-related factors, and the importance of public participation shall be enhanced.

Viability- The final success of the system depends on the economic cost that should not only integrate implementation, but maintenance and monitoring costs as well. In order to contain cost, the number of indicators is advised to be kept to a minimum, by having them to overlap in functions.

While there are several ongoing efforts, there are still problems to create ESI due to the confronting interests at play. Due to the lack of a clear methodology, there is a tendency to select indicators randomly and based more on an impact perspective, rather than on a preventive activity. Reactive, impact-related measures are not likely to be an appropriate example for a long-term sustainable strategy. According to Lundqvist et al, the problem with ESI is that they are often developed in a custom made fashion, without a structured framework for identifying indicators.

In order to support the selection of sustainability indicators for a system, there needs to be a scientific basis. This basis will be played in this thesis by the implementation of the LCA.

Steps to Develop Indicators

The development of sustainability indicators is a complex process and calls for a flexible problem solving approach, instead of a rigid procedure.

It is of the utmost importance that ESI's are connected to the vision and goals of the UWS. For this reason, the first step in the process towards defining ESI is to define the vision and specific table of goals for the city of Zaragoza, as above mentioned.

It has been suggested that, to successfully accomplish the process of selecting sustainability indicators a method package is required. The definition of a "method package" is the composition of basic methods with a specific purpose in the problem solving process. The methods used to properly develop sustainability indicators will include:

- Conceptualization of the problem definition, and description of the existing system with its limitations.
- Listing and description of indicators including the parameters of time, location, target population, and system process.
- Indicators selection from research, based on capacity to best describe the system with the least number of indicators.
- Interpretation of indicator results by LCA results (SimaPro and EcoIndicator 99).
- End user validation through re-assessment of representative indicators via an expert panel/workshops.
- Interpretation of data and facts for future comparison studies with other SWICTH cities.

f. Bellagio Principles Definition

The Bellagio Principles are one of the best-known and most comprehensive sets of guidelines for the development of sustainability indicators. These principles serve as a guide during the sustainability assessment process involving choice, interpretation, and communication of results.

g. Bellagio methodology

Any change assessment relies on a frame of reference to identify if change has taken place, and to set a context for judging this change both qualitative (positive or negative) as well as quantitatively.

The Bellagio Principles are based on ten essential guidelines;

1) Establish a common, clear vision and goals.

2) Holistic perspective by:

- Including a review of the whole system, as well as its parts.
- Considering the well-being of social, ecological, and economic sub-systems; their state, as well as the direction and rate of change of that state; of their constituent parts; and the inter-action between parts.
- Considering both positive and negative consequences of human and ecological systems, both in monetary and non-monetary terms.

3) Essential elements to consider are: equity, overconsumption, resource use, human rights, ecological conditions, and economic development.

4) Scope: time horizon and geographical scale of study (local, national, international)

5) Practicality: links between vision and goals, manageable number of indicators, and standardize measurement for comparison purposes.

6) Openness: data accessible to all, making explicit mention of assumptions and interpretations.

7) Effective Communication in order to address the needs of the audience and engage decision-makers, by avoiding scientific jargon.

8) Broad Participation by obtaining representation from technical experts, social groups, politicians, business owners, etc to ensure maximum representation of the cultural values

9) Ongoing Assessment. It shall be continuous in order to detect trends. Moreover, it must be iterative and responsive to change, in order to adjust indicators as new insights are unveiled.

10) Institutional Capacity. Finally, it should consider the institutional capacity for the on-going assessment by the local institutions.

h. Case Studies

There are few publications where LCA has been applied, particularly for an Urban Water System. In this section, case studies relevant to this application will be analyzed. A brief summary includes a review on the scope, system boundaries and results of each study. Also particular observations and limitations that may be useful for conducting this research were noted.

While it is possible to find studies on separate processes within the urban water system, for instance for a wastewater treatment plant analysis, there are few cases for an entire Urban Water System, including all its processes.

The Zaragoza System fits under the type of conventional, large-scale urban system typical of an industrialized city. Such a system covers the basic health and safety objectives for water quality, and counts with an efficient purification system to remove pollutants. In developed countries, the main sustainability challenges for an UWS happen because water managers have focused more on today's technical problems than in future pressure drivers such as population and urbanization growth, and lately, climate change.

Case studies have identified the following main driving forces causing negative impacts on the sustainability on an Urban Water System:

- Energy consumption (Sven *et al.* 2004).
- Sludge Management (Mario *et al.* 2001).
- Wastewater Treatment Plants have the most significant impact within the urban system (Penagos, 2006; Rihon, 2002).

Based on case studies, the different management strategies to reduce environmental impacts have included;

- Energy efficiency, Cogeneration, and Renewable technologies.
- Optimization of WWTP design.
- Better management of WWTP.
- Pollutant prevention at the source.

The following tables describe the main impacts for the different processes within an Urban Water System:

Drinking water treatment	
Environmental burdens attributed to:	Energy use to produce potable water
	Chemical use to counteract for water quality[1]
Impact reduction actions:	Renewable energies
	Chemical use substitution

[1] Barrios

Wastewater treatment	
Environmental burdens attributed to:	Energy used to treat wastewater
	Evaluation of technologies used
	Eutrophication and toxicity[2]
	Chemical use to counteract for water quality[1]
Impact reduction actions:	Renewable energies
	Reuse of tertiary water
	Proper sludge management
	Pollution abatement at the source[3]

[1] Barrios
[2] Almudena *et al*. 2004
[3] Hazem *et al*. 2001

Sewage sludge management	
Environmental burdens attributed to:	Toxicity by heavy metals[4]
	Energy consumption (transport cost, incineration)
Impact reduction actions:	Cogeneration (energy from digestion, incineration)
	Recycling
	Proper sludge management
	Pollution abatement at the source (heavy metal content)

[4] Almudena *et al*. 2005

5. SimaPro Results

The LCA intends to show the aspects of the Urban System which represent the largest burdens to the environment. A base case was constructed to represent the current operations of ZUWS. Life Cycle Inventory data from energy, chemicals, and emissions for soil, water, and air were collected.

i. Inventory analysis

The data collected to develop the SimaPro model was obtained from the Zaragoza Municipality Agenda 21 and the Infrastructure Department. Data from Casablanca was obtained through field visits assisted by the plant lead engineer, Mr. Angel Monux. Data from Almozara and Cartuja wastewater treatment plants was obtained through field visits assisted by the plant lead engineer Mr. Antonio Silva. Other data and calculations for the ZUWS were collected from the previous thesis research by Mr. Guillermo Penagos (2006).

The LCA is designed to unveil the largest burdens to the sustainability of the ZUWS. As an initial step in this exercise, a **base case** model was developed to represent the current operations of ZUWS. This Life Cycle Inventory included data collection from energy consumption and their respective energy sources (Coal, Nuclear), chemical inputs (Chlorine, Aluminum Sulphate, Sodium

Hipochlorite), as well as emissions to soil (Heavy Metals), and water (BOD, COD, TotalN and TotalP).

The electricity, chemical consumption, and discharge pollutants to water and soil data for the water extraction, potable Water, and wastewater treatment were based on highly accurate, site-specific data at their respective plants.

On the other hand, air emissions (CO_2) are based on calculations from the energy sources in Spain and the emission factors for the EU. While calculations are based on credible assumptions, these data do not have the degree of certainty that site-specific data have, and hence, the quality of this data is rated as medium.

In the Distribution phase, a calculation based on assumptions is made for the Breaking pressure tanks ("Aljibes") found in Zaragoza. In this thesis, the average energy necessary to pump the water to every household within an apartment block was determined. In order to obtain these results several assumptions were made such as: number of floors per building (6), average height per floor (3m), number of people per flat (3), and pump efficiency (30%) (Anex 4). While the reasoning in these calculations is consistent, the quality of this data is rated as medium.

Process	**Life cycle component**	**Basis of data**	**Data Quality**	**Inventory Information**
Water Extraction	Energy Consumption	Site specific measurements	High	Municipality of Zaragoza
	Air Emissions	Calculation of CO_2 Emissions from electricity source	Medium	Ministerio de Industria, Turismo y Comercio de España
Pretreated Potable Water	Energy Consumption	Site specific measurements	High	Municipality of Zaragoza
	Chemical Inputs	Chlorine, Aluminun Sulphate, Carbon	High	Casablanca Engineering Department
	Air Emissions	Calculation of CO_2 Emissions from electricity source	Medium	Ministerio de Industria, Turismo y Comercio de España
Wastewater Treatment Plants	Energy Consumption	Site specific measurements	High	WWTP Engineering Department
	Emissions to Water	BOD, COD, Nitrate	High	WWTP Engineering Department
	Emissions to Soil	Heavy Metals	Medium	Municipality of Zaragoza
Drinking Water Transport	Energy Consumption (Aljibes)	Generic Estimates for Aljibes	Medium	Pump Consumption Calculation
	Air Emissions	Calculation of CO_2 Emissions from electricity source	Medium	Ministerio de Industria, Turismo y Comercio de España

Stormwater	Energy Consumption	Generic Estimates	Medium	Municipality of Zaragoza
	Air Emissions	Calculation of CO_2 Emissions from electricity source	Medium	Municipality of Zaragoza
	Pollutant Event Concentrations	Unit Loads (kg/Impervious hectares*Year)	Medium	Frontiers in Urban Water Management

Table 1. Life Cycle Inventory for ZUWS

4. Environmental Impact Assessment

Life Cycle Impact Assessment is the phase aimed at understanding and evaluating the magnitude and significance of potential environmental impacts based on the Inventory Data. The Life Cycle Inventory data is characterized using several impact categories.

a. Eco-Point 99/ Impact Categories- The first step in the LCIA is the selection of the most appropriate impact categories. In this research the impact categories are based from the Eco-Point 99 (E) procedure. The impact categories considered are as follows:

- 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.

Eco-Indicator has a damage assessment step. This means that the impact category results calculated in the Characterization steps, are added to form damage categories.

There are three damage categories:

1. Human health.
2. Ecosystem quality.
3. Resources.

b. Assessment Method

As previously mentioned, the assessment method of choice for this thesis, Eco-indicators 99, is damage oriented. Even if this has been proven as one of the best methods overall, unfortunately it has some shortcomings. Of special relevance for this work is the inexistent assignment of damage factors to nutrients and COD with regards to euthrophication, so important in the analysis of a water system. Being aware of the potential significance of this, it was decided to calculate characterization factors for phosphorous and COD, based on the corresponding factors from the Eco-indicator 95, as done in Mr. Mohamed Mahgoub master's thesis. The following calculations were based on the characterization factor for total Nitrogen published in the Eco-invent report No. 3 (2004): 18.8 (PDF x m^2 x yr/kg)

Substance	Eco-indicator 95 Characterization factor	Calculated Characterization factor
N	0.42 (kg PO^4)	44.76 (PDF x m^2 x yr/kg)
COD	0.022 (kg PO^4)	0.98 (PDF x m^2 x yr/kg)
P	3.06 (kg PO^4)	136.97 (PDF x m^2 x yr/kg)

PDF refers to Potentially Disappeared Fraction of species

Table 2. Eutrophication Factoring

c. Schematic of Zaragoza Urban Water System

One of the results of SimaPro is a schematization of the ZUWS, shown as a "network". This network contains all the processes and materials entered into the system, but will only show those with a significant environmental impact. The number of processes shown is depends on a selected environmental cutoff level. Those contributing less may not be shown in the network, but their contribution is nevertheless still accounted for in the model. Within each box of the network, the line bar at the right expresses the environmental load to the system. The red bar represents the "hotspots" in terms of negative environmental loads to the system, while the green bar indicates a positive environmental contribution to the system.

The network depicted below includes the following processes of the ZUWS; Pretreated Potable Water, Drinking Water Transport, Electricity for Almozara and Cartuja, and Wastewater Treatment. While the processes Water Extraction and Wastewater Transport were included in the network, they are not shown due to the cutoff level, indicating that their environmental load is not as significant as that of the other processes currently reflected. For a full depiction of the Base Case Network refer to Annex 12.

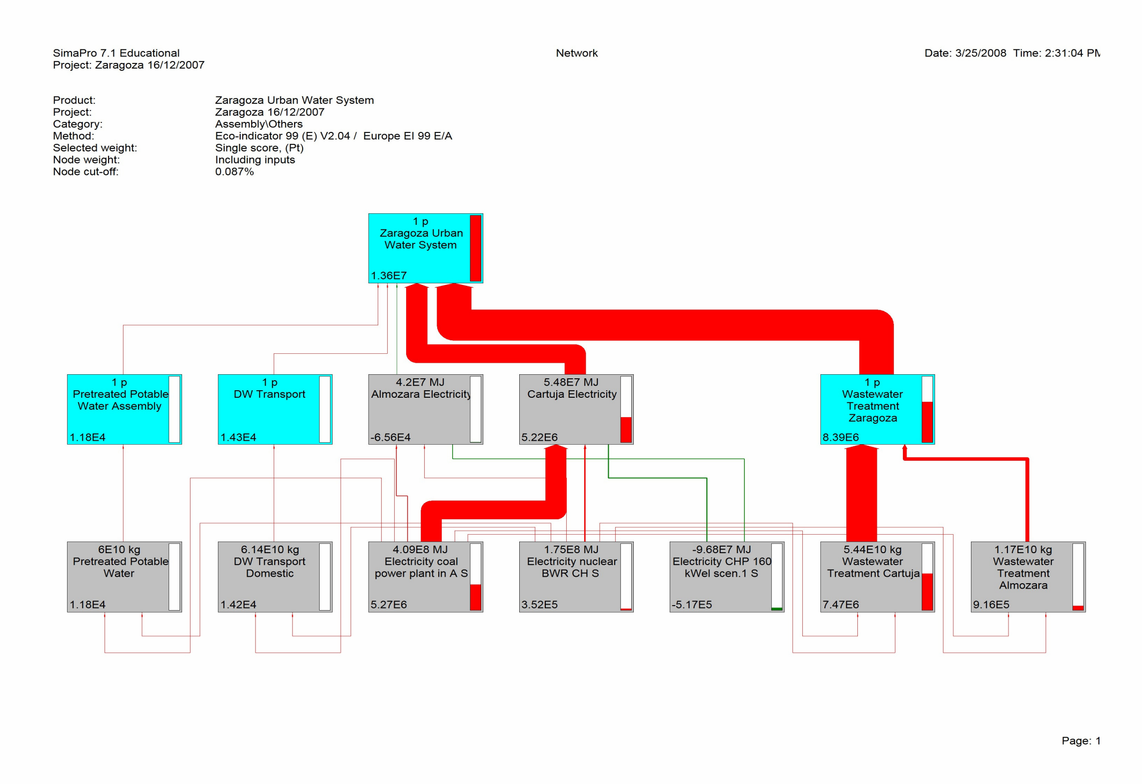


Figure. 7 SimaPro Schematic Zaragoza Urban Water System

Simply observing the size of the red bars, it can be seen that the biggest environmental burdens to the ZUWS are Wastewater Treatment Cartuja, Electricity Load Cartuja, and Wastewater Treatment Almozara.

The literature review has shown an agreement with these identified "hotspots" for an Urban Water System. These environmental loads can be attributed to the following factors;

- Electricity Load Cartuja ➔ Energy consumption.
- Wastewater Treatment Cartuja & Almozara ➔ Sludge Management, Heavy Metal content.
- Wastewater Treatment Plants represent the most significant impact within the urban system ➔ Wastewater Treatment Cartuja & Almozara.

It is interesting to note that, while Almozara WWTP uses large amounts of electricity just as Cartuja WWTP does, the environmental load from Almozara are transformed into positive environmental contributions to the ZUWS. Such impact reduction activity is also confirmed by the literature review in the following factor;

- Cogeneration ➔ Energy from digestion, incineration.

5. Results of Impact Assessment

In the goal and scope of this study, the characterization chosen to evaluate the ecological impacts has been the Eco-Indicator 99. This is a complex framework, but the obtained results and their meanings are easier to understand and evaluate within its framework, giving it an advantage to decision makers.

While the network interpretation is helpful in identifying the loads and contributions of the system, the LCI analysis will give a more detailed quantitative analysis of the contributions from energy flows, chemical inputs, and emissions based on Eco-point units. An **Eco-point** is a measure of the overall environmental impact of a particular product or process, in our case measured by the environmental impact categories established by the Eco-Indicator 99. It is important to note that eco-points measures negative impacts, therefore a positive eco-point number means an impact, while a negative eco-point number is a positive contribution to the process or system. **Table 3** shows the total contributions in Eco-points of the different processes within the ZUWS to the selected impact categories.

i. Critical Processes of the ZUWS

The assessment of the entire urban system can identify the critical environmental processes based in the percentage of eco-points obtained. The contribution assessment for the processes in the Zaragoza Urban Water System showed the following results:

- The WWTP's contributed to the environmental load with 60% eco-points for the total system.
- The Electricity load for Cartuja WWTP contributed 41% eco-points
- The WWTP's **pollutant emissions** for Cartuja and Almozara and the **electricity emissions** for Cartuja made up 100% of the eco-points contribution to the entire system.

Impact Category	Unit	Percent	Total	Extracted Water	Pretreated Potable	Transport Water	Almozara Electriity	Cartuja Electricity	Wastewater treatment
Total [Percentage]	**%**	**100%**		**0,00%**	**0,08%**	**0,10%**	**-0,46%**	**40,72%**	**59,56%**
Total [Ecopoints]	**Pt**	**100%**	**1,41E+07**	**2,07E+01**	**1,18E+04**	**1,43E+04**	**-6,56E+04**	**5,75E+06**	**8,41E+06**
Carcinogens	Pt	5%	6,53E+05	1,49E+00	7,25E+02	1,02E+03	1,12E+04	4,35E+05	2,05E+05
Respiratory organics	Pt	0%	4,78E+02	2,17E-03	3,38E+00	1,49E+00	-5,96E+01	5,33E+02	0,00E+00
Respiratory inorganics	Pt	4%	5,16E+05	1,79E+00	1,19E+03	1,23E+03	4,49E+03	5,09E+05	0,00E+00
Climate change	Pt	9%	1,21E+06	4,19E+00	2,06E+03	2,89E+03	1,05E+04	1,20E+06	0,00E+00
Radiation	Pt	0%	6,92E+04	2,31E-01	1,71E+02	1,65E+02	1,74E+03	6,72E+04	0,00E+00
Ozone layer	Pt	0%	4,77E+02	1,65E-03	2,35E+00	1,17E+00	3,87E+00	4,70E+02	0,00E+00
Ecotoxicity	Pt	58%	8,25E+06	1,50E-01	8,16E+01	1,03E+02	6,64E+02	4,32E+04	8,21E+06
Eutrophication	Pt	0%	5,38E+04	1,89E-01	1,20E+02	1,30E+02	1,08E+02	5,34E+04	0,00E+00
Land use	Pt	2%	2,58E+05	8,67E-01	6,05E+02	6,16E+02	5,43E+03	2,51E+05	0,00E+00
Minerals	Pt	0%	3,86E+03	1,56E-02	8,78E+00	1,08E+01	-2,41E+02	4,08E+03	0,00E+00
Fossil fuels	Pt	22%	3,10E+06	1,18E+01	6,86E+03	8,09E+03	-9,93E+04	3,19E+06	0,00E+00

Table 3. Total Environmental Impacts for ZUWS processes

The total ZUWS impact assessment can also be evaluated based on a weighted table. In this graphical representation the environmental loads of a particular process are more easily identified based on the impact categories it contributes to;

- Ecotoxicity category scores $8,25e^{+06}$ points (58% of the total) entirely from the WWTP's contribution from Cartuja and Almozara.

- Fossil fuels category scores $3,10e^{+06}$ points (22%) for Cartuja Electricity.

- Additional noticeable category contributions are in the climate change, carcinogens categories, and respiratory inorganics mostly due to Cartuja Electricity and WWTP toxic emissions.

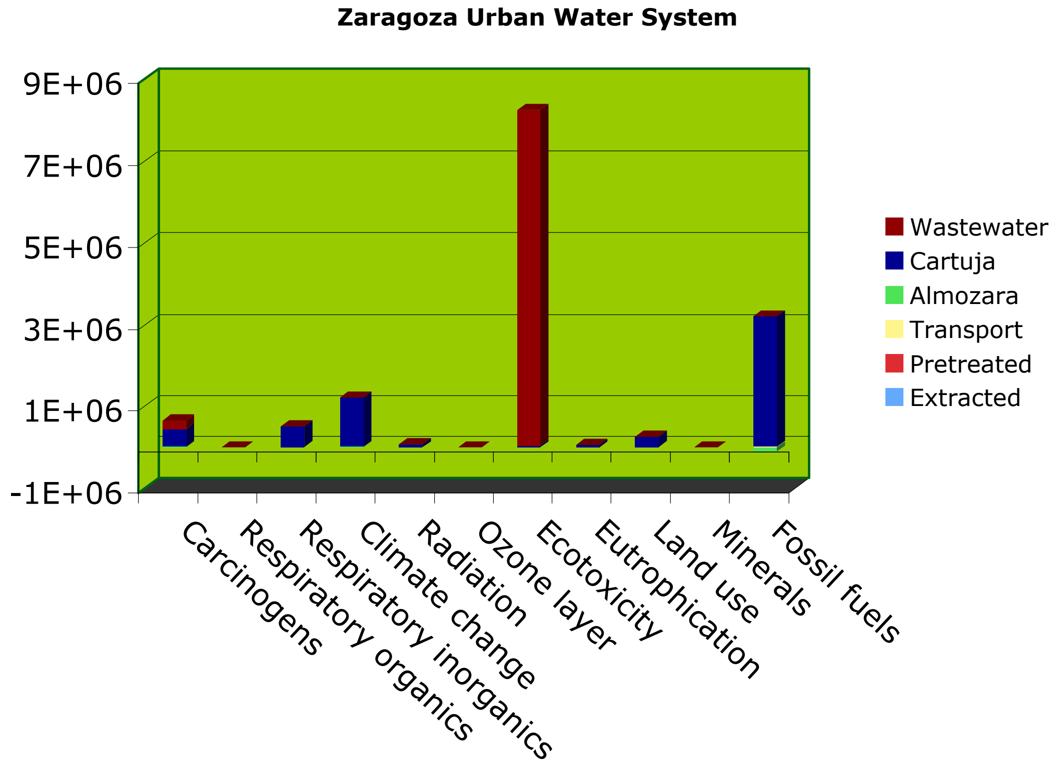


Figure 8. Total Impact Categories Base Case

Figure 8. indicates graphically the largest impact to ecotoxicity from the Wastewater treatment process. From Cartuja Electricity it is also clear the major impact categories come mainly in fossil fuels, followed by climate change, carcinogens and respiratory inorganics at smaller but yet significant contributions.

The process results, identified as the ones contributing most to the negative and positive environmental impacts of the system (Wastewater Treatment, Almozara & Cartuja Electricity), are analyzed individually in the following section. The processes that had negligible contributions to the system are included in the Anex 5,6,7.

d. Impact of Wastewater Treatment

The environmental impacts for the two wastewater treatment plants (Cartuja & Almozara) are measured in eco-points. It is important to note that for modeling requirement purposes, the Electricity consumption of the treatment plants were modeled separately from the rest of the processes within the Wastewater Treatment Plants. Therefore, the major impact category for Cartuja & Almozara WWTP's in the model is the Ecotoxicity. This result is due to the sludge material content in heavy metals, which are inputs in the form of emissions to soil. In terms of plant contributions, Cartuja represents 89% of the total impact with $7,3e^{+06}$ eco-points for ecotoxicity and $1,7e^{+05}$ in carcinogens. The higher percentage for Cartuja's impact can be attributed to the larger loads

of wastewater treated, covering 85% of the population, versus 11% for Almozara, which contributed by 40% or 9,1e^{+05} eco-points to ecotoxicity and 3,42e^{+04} to carcinogens category.

Impact Category	Unit	Percentage	Total	Cartuja WWT	Almozara WWT
Total [Percentage]	%	100%		88,81%	8,41E+06
Total [Ecopoints]	Pt	100%	8,41E+06	7,47E+06	9,41E+05
Carcinogens	Pt	2%	2,05E+05	1,71E+05	3,42E+04
Respiratory organics	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Respiratory inorganics	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Climate change	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Radiation	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Ozone layer	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Ecotoxicity	Pt	98%	8,21E+06	7,30E+06	9,07E+05
Eutrophication	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Land use	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Minerals	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Fossil fuels	Pt	0%	0,00E+00	0,00E+00	0,00E+00

Table 4. WWTP Environmental Impacts for ZUWS processes

Figure 9. below best represents the graphical representation for the negative contributions per impact category. It is clear that WWTP contribute mainly to the ecotoxicity category and that Cartuja due to its larger treatment capacities contributes more than 75% to this category.

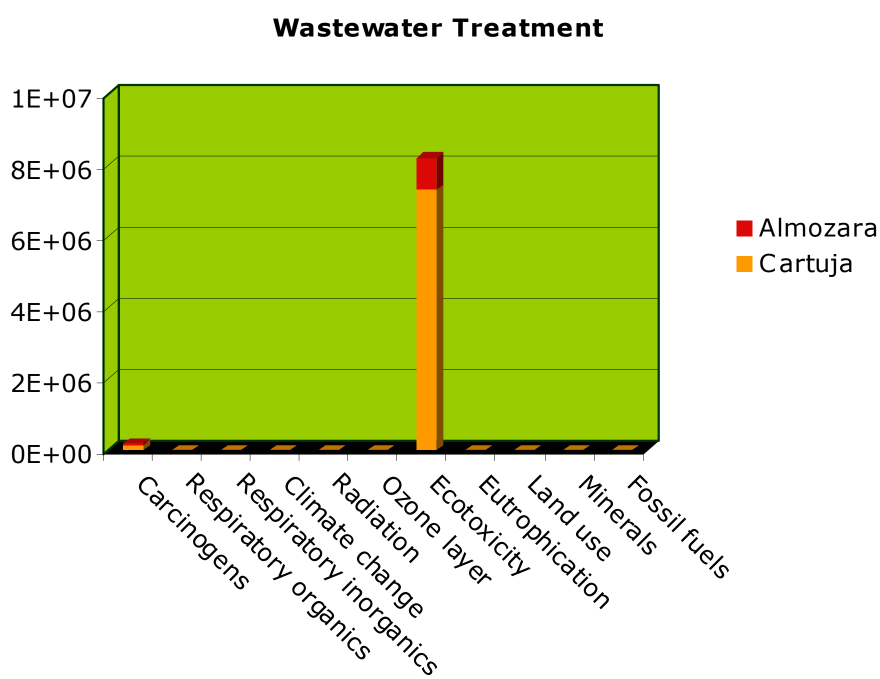


Figure 9. WWTP Impact Categories Base Case

e. Impacts of Almozara Electricity

Almozara electricity results are measured in full eco-points. It is important to take into account that Almozara generates 75% of its energy requirements from biogas recovery. (See table below for 2007 data).

2007	Total Electricity	Bought Electricity	Generated Energy
kwh	2.289.870	659.070	1.630.800

In terms of Electricity consumption, the energy sources used as inputs for the model were based on data from the national balance of energy sources in Spain, and rounded as coal (70%) and nuclear (30%).

Almozara electricity has a positive overall contribution regarding ZUWS environmental load (i.e it has negative ecopoints -6,56e^{+04}), due to its cogeneration activities. While coal (the highest impact category in the form of ecotoxicity with 1,34e^{+05} eco-points) and nuclear processes have negative contributions of 2,45e^{+04} eco-points, the positive cogeneration contributions balance the impact scale with -2,24e^{+05} eco-points, where negative eco-points means a benefit to the environment, as explained.

Additionally, not only is the fossil fuels category reduced in the cogeneration process, the CO_2 emissions are reduced as well and thus, its global climate change impact. The relation between the energy source and the CO_2 emissions can be found in Annex 5.

The Almozara case is a good example on how to reduce negative environmental loads of an urban water system, mainly by recycling energy (cogeneration). Another option that will be presented in the alternative scenarios is the implementation of alternative energy sources (renewable energies).

Impact Category	Unit	Percentage	Total	Coal Generation	Nuclear Generation	Cogeneration
Total [Percentage]	%	100%		-204,60%	-37,34%	341,94%
Total [Ecopoints]	Pt	100%	-6,56E+04	1,34E+05	2,45E+04	-2,24E+05
Carcinogens	Pt	-17%	1,12E+04	1,13E+04	1,17E+02	-2,62E+02
Respiratory organics	Pt	0%	-5,96E+01	1,59E+01	6,87E-01	-7,62E+01
Respiratory inorganics	Pt	-7%	4,49E+03	1,32E+04	4,94E+02	-9,19E+03
Climate change	Pt	-16%	1,05E+04	1,64E+04	1,57E+04	-2,17E+04
Radiation	Pt	-3%	1,74E+03	7,08E+01	1,69E+03	-2,29E+01
Ozone layer	Pt	0%	3,87E+00	3,75E+00	8,88E+00	-8,75E+00
Ecotoxicity	Pt	-1%	6,64E+02	1,12E+03	3,31E+01	-4,87E+02
Eutrophication	Pt	0%	1,08E+02	1,40E+03	4,44E+01	-1,34E+03
Land use	Pt	-8%	5,43E+03	1,36E+03	5,28E+03	-1,21E+03
Minerals	Pt	0%	-2,41E+02	9,24E+01	2,71E+01	-3,60E+02
Fossil fuels	Pt	151%	-9,93E+04	8,92E+04	1,05E+03	-1,90E+05

Table 5. Almozara Environmental Impacts for ZUWS

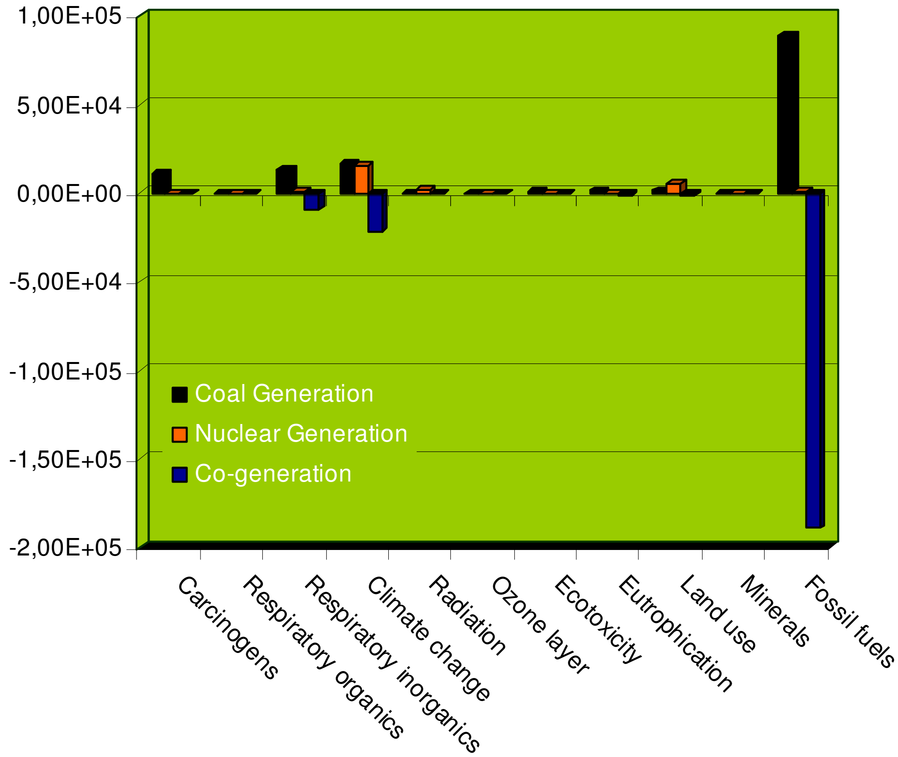


Figure 10. Almozara Impact Categories Base Case

Figure 10. represents the impact contributions from the Almozara energy sources. It is clear that Co-generation has positive contributions to the system mainly in the fossil fuels category. Nuclear and coal sources indicate negative impacts to the Almozara Electricity in all categories.

f. Impacts of Cartuja Electricity

Cartuja electricity results are measured in full eco-points as well. Unlike Almozara, Cartuja treatment plant produces only 8% of its electricity through heat recovery from the sludge incineration phase (See table below for 2007 data). While this is a positive contribution to the ZUWS, the cogeneration contribution to the ZUWS could still be significantly upgraded.

2007	Total Electricity	Bought Electricity	Generated Energy
kwh	30.335.800	27.658.400	2.677.400

Similarly, energy sources for Cartuja came from data for national balance of energy sources in Spain, and rounded to 70% coal and 30% nuclear.

Cartuja Electricity has a significant negative contribution to the ZUWS environmental load. As can be observed in the processes breakdown, coal and nuclear sources have negative contributions of 5,11e^{+06} and 9,33e^{+05} eco-points

respectively, making up to 105% total negative contributions, while the positive cogeneration contributions are -2,39e^{+05} eco-points, hence reducing the negative environmental contribution for Cartuja by -5%.

Impact Category	Unit	Percentage	Total	Coal Generation	Nuclear Generation	Cogeneration
Total [Percentage]	%	100%		88,87%	16,22%	-5,10%
Total [Ecopoints]	Pt	100%	5,75E+06	5,11E+06	9,33E+05	-2,93E+05
Carcinogens	Pt	8%	4,35E+05	4,31E+05	4,47E+03	-3,43E+02
Respiratory organics	Pt	0%	5,33E+02	6,06E+02	2,62E+01	-9,95E+01
Respiratory inorganics	Pt	9%	5,09E+05	5,02E+05	1,88E+04	-1,20E+04
Climate change	Pt	21%	1,20E+06	6,26E+05	6,00E+05	-2,84E+04
Radiation	Pt	1%	6,72E+04	2,70E+03	6,45E+04	-2,99E+01
Ozone layer	Pt	0%	4,70E+02	1,43E+02	3,38E+02	-1,14E+01
Ecotoxicity	Pt	1%	4,32E+04	4,26E+04	1,26E+03	-6,36E+02
Eutrophication	Pt	1%	5,34E+04	5,35E+04	1,69E+03	-1,75E+03
Land use	Pt	4%	2,51E+05	5,17E+04	2,01E+05	-1,57E+03
Minerals	Pt	0%	4,08E+03	3,52E+03	1,03E+03	-4,71E+02
Fossil fuels	Pt	55%	3,19E+06	3,40E+06	4,00E+04	-2,48E+05

Table 6. Cartuja Environmental Impacts for ZUWS

Based on the graphical representation of the impact categories, it is noticeable that the largest impacts for the Cartuja Electricity process is the use of coal, contributing with 3,40e^{+06} eco-points to the fossil fuel category, 6,26e^{+05} to the climate change, and approximately 5e^{+05} to both the respiratory inorganics, and the carcinogens. The impact categories mainly affected by the nuclear source are valued in land use at 2e^{+05} eco-points and radiation at 6,45e^{+04} eco-point. It is clear that the source of energy generation will be reflected in the impact categories affected. Moreover, the balance in between sources will also affect the percentile contribution to the eco-point valuation.

The relation between the energy source and the CO_2 emissions detailed in the Almozara case can be applied to the Cartuja exercise as well (Annex 5).

The co-generation positive contributions for Cartuja Electricity can also be noted with -2,93e^{+05} eco-points. The important thing to keep in mind here is the potential for improvement in the positive performance of this process if the co-generation percentage were increased,as today the value is similar to that of Almozara in absolute value, but insignificant when taken into account its much larger processed volumes.

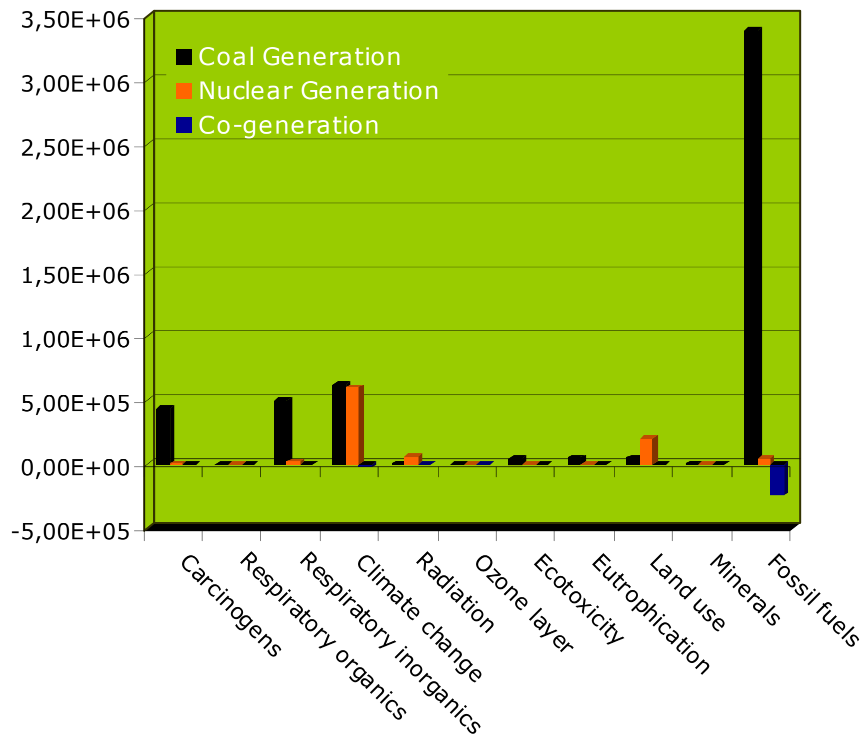


Figure 11. Cartuja Impact Categories Base Case

The Cartuja plant, unlike the Almozara case, is an example on what can be improved to reduce the negative environmental loads to an urban water system, mainly by exploring alternative energy sources, and by recycling of energy as well as other materials within the system and/or process. The reflection of these results will be later applied to alternative scenarios developed for the ZUWS to promote sustainability.

6. Scenario Analysis

Aside from the base case presented above, two additional ZUWS cases were investigated to compare the environmental performance of alternative system scenarios.

The detailed description of the proposed scenarios is as follows;

a. **Expected Scenario with Business as Usual Strategy**:

The factors considered for the projection to 2020 are as follows;

- Population Increase ➔ Increased Water & Energy Consumption

- Reduced Precipitation → Increased Pollutant Concentration

The expected scenario for the year 2020 includes a characteristic increase in driving pressures, mainly population growth (30%) and the consequent rise in energy, chemical & water consumption. Additionally, climate change pressure will cause a decrease in precipitations (15%) with a consequent increase in the concentration of pollutant loads (30%).

b. **Expected Scenario with Action Strategy**:

The factors considered for the Expected Scenario with Action Strategy are as follows;

- Renewable Energies → Reduction of CO_2
- New Source of Water → Reduction of Chemical Inputs
- Cartuja Biosolids Cogeneration → Reduction of coal fuel

This expected scenario includes the additional future pressures mentioned in the first case scenario, but to counteract them, sustainable activities (action strategy) have been factored in to address critical processes. In the ZUWS, the most critical process identified was the electricity consumption of the WWTP's, particularly the Cartuja. It is due to this that Action Strategy introduces the use of renewable energies. Zaragoza has the characteristic wind from the Cierzo, and it counts with plenty of free surface in the surrounding barren areas of the ZUWS; it is for this reason that wind generation was the chosen renewable energy type. Such an activity has a direct effect on the reduction of the CO_2.

Additionally, by increasing the cogeneration activities from biosolids and digestion at Cartuja to 50%, the electricity consumption and CO_2 emissions would be reduced significantly.

Results of proposed scenarios

i. Expected Scenario with Business as Usual Strategy

- Population Increase to 1 Million → Increased Energy Consumption & Sludge Pollution by 30%
- Reduced Precipitation 15% → Increased Pollutant Concentration in Storm-water by 15%

Impact Category	Unit	Percent	Total	Extracted Water	Pretreated Potable	Transport Water	Almozara Electricity	Cartuja Electricity	Wastewater treatment
Total [Percentage]	%	100%		0,00%	0,02%	0,06%	0,09%	72,86%	26,96%
Total [Ecopoints]	Pt	100%	4,95E+07	1,73E+03	1,17E+04	3,17E+04	4,28E+04	3,61E+07	1,34E+07
Carcinogens	Pt	6%	3,05E+06	3,22E+00	3,27E+02	1,99E+03	6,32E+03	2,73E+06	3,15E+05
Respiratory organics	Pt	0%	3,34E+03	4,53E-03	1,63E+00	3,06E+00	-5,93E+00	3,34E+03	0,00E+00
Respiratory inorganics	Pt	6%	3,21E+06	3,76E+00	5,57E+02	3,04E+03	5,76E+03	3,20E+06	0,00E+00
Climate change	Pt	15%	7,55E+06	1,70E+03	7,20E+03	1,03E+04	1,37E+04	7,52E+06	0,00E+00
Radiation	Pt	1%	4,22E+05	2,02E-02	7,68E+01	1,26E+01	6,98E+02	4,21E+05	0,00E+00
Ozone layer	Pt	0%	2,95E+03	1,07E-03	1,11E+00	6,76E-01	3,84E+00	2,95E+03	0,00E+00
Ecotoxicity	Pt	27%	1,33E+07	3,18E-01	3,73E+01	2,03E+02	5,42E+02	2,71E+05	1,30E+07
Eutrophication	Pt	1%	3,36E+05	4,00E-01	5,58E+01	3,22E+02	5,38E+02	3,35E+05	0,00E+00
Land use	Pt	3%	1,58E+06	3,87E-01	2,72E+02	2,40E+02	2,59E+03	1,58E+06	0,00E+00
Minerals	Pt	0%	2,56E+04	2,63E-02	3,97E+00	1,95E+01	-9,15E+00	2,56E+04	0,00E+00
Fossil fuels	Pt	40%	2,00E+07	2,54E+01	3,14E+03	1,56E+04	1,27E+04	2,00E+07	0,00E+00

Table 7. Total Environmental Impacts for ZUWS for Business as Usual Strategy

The assessment of the entire urban system can identify the critical processes for the Business as Usual Strategy. The contribution assessment for the processes in the Zaragoza Urban Water System showed the following results:

- The Cartuja Electricity now contributes more heavily to the environmental load with **almost 73%** of the total eco-points incurred by the system. On the other hand, Almozara contribution is negligible $4,28e^{+04}$. The smaller contribution from Almozara is again most likely due to the smaller wastewater treatment volumes it processes, and its more significant co-generation activities.

- Another major contributor is the WWTP responsible of almost 23% for the total system impact, with $1,34e^{+07}$ eco-points

It is interesting to note that the major impact category for the electricity for Cartuja and Almozara is in the form of coal at $1,27e^{+06}$. Due to Almozara's positive contributions in the form of co-generation, the negative eco-point contribution is counter-balanced in its final eco-point count. On the other hand, the coal eco-points for Cartuja are reflected as the main source of the negative contributions from the Electricity.

The contributions to the system from the other processes within the urban water system are negligible.

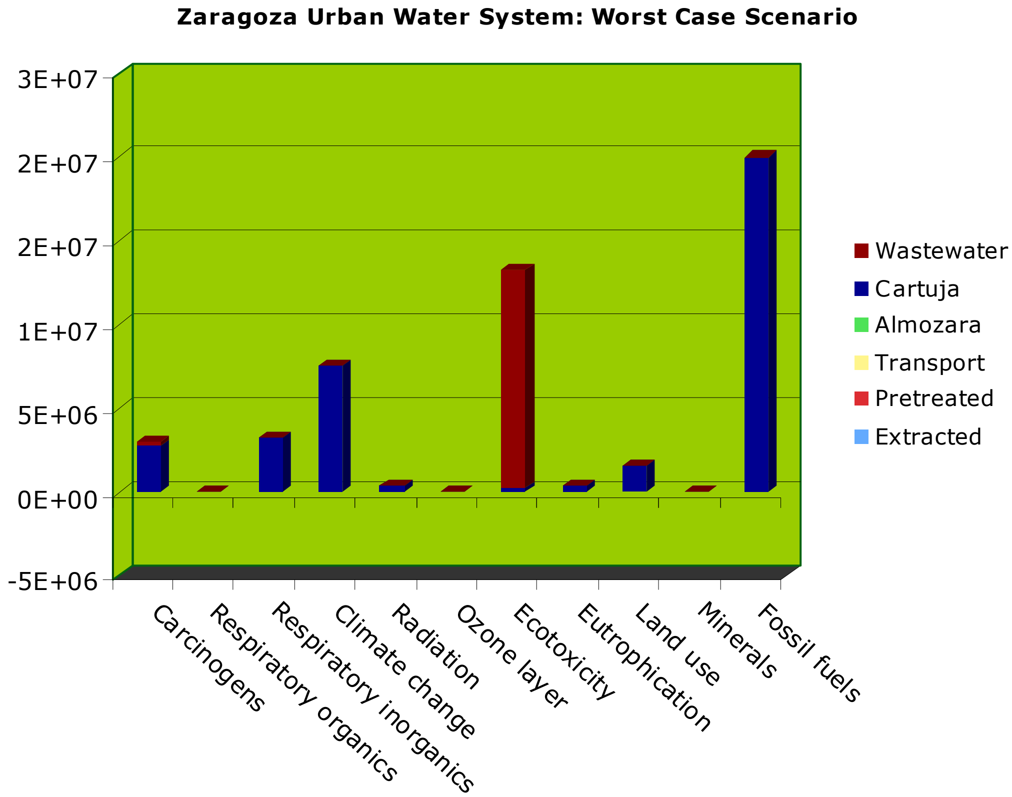


Figure 12. Total Impact Categories Business as Usual Strategy

The total ZUWS impact assessment can also be graphically evaluated based on the above graph. In this representation, the environmental loads of a particular process are more easily identified based on the impact categories it contributes to;

- Fossil fuels category scores $2{,}00e^{+07}$ points (40% of the total for the system) entirely from the energy consumption contribution from Cartuja and Almozara.

- Ecotoxicity category scores $1{,}33e^{+07}$ points (27% of the total for the system) entirely from the WWTP's pollutant load's contribution from Cartuja and Almozara.

- Additional noticeable category contributions are: climate change at 15% with $7{,}55e^{+06}$ ecopoints, carcinogens and respiratory inorganics at 6% each. All of these are mostly a consequence of Cartuja Electricity and WWTP toxic emissions.

j. Impacts of Cartuja Electricity for Business as Usual Strategy

Cartuja Electricity has a negative contribution of 3,61e^{+07} eco-points. As can be observed in the processes breakdown, coal and nuclear sources have negative environmental contributions of 3,21e^{+07} and 5,85e^{+06} eco-points respectively, making up to 105% total negative contributions, while the positive cogeneration contributions are -1,84e^{+06} eco-points, hence reducing the negative environmental contribution for Cartuja by -5%.

Impact Category	Unit	Percentage	Total	Coal Generation	Nuclear Generation	Cogeneration
Total [Percentage]	%	100%		88,87%	16,22%	-5,10%
Total [Ecopoints]	Pt	100%	3,61E+07	3,21E+07	5,85E+06	-1,84E+06
Carcinogens	Pt	8%	2,73E+06	2,70E+06	2,81E+04	-2,15E+03
Respiratory organics	Pt	0%	3,34E+03	3,80E+03	1,64E+02	-6,25E+02
Respiratory inorganics	Pt	9%	3,20E+06	3,15E+06	1,18E+05	-7,54E+04
Climate change	Pt	21%	7,52E+06	3,93E+06	3,76E+06	-1,78E+05
Radiation	Pt	1%	4,21E+05	1,69E+04	4,05E+05	-1,87E+02
Ozone layer	Pt	0%	2,95E+03	8,97E+02	2,12E+03	-7,18E+01
Ecotoxicity	Pt	1%	2,71E+05	2,67E+05	7,92E+03	-3,99E+03
Eutrophication	Pt	1%	3,35E+05	3,36E+05	1,06E+04	-1,10E+04
Land use	Pt	4%	1,58E+06	3,24E+05	1,26E+06	-9,88E+03
Minerals	Pt	0%	2,56E+04	2,21E+04	6,47E+03	-2,96E+03
Fossil fuels	Pt	55%	2,00E+07	2,13E+07	2,51E+05	-1,55E+06

Table 8. Cartuja Environmental Impacts for ZUWS for Business as Usual Strategy

Based on the graphical representation of the impact categories, it is noticeable that the largest impacts for the Cartuja Electricity process is the use of coal, contributing with 2,13e^{+07} eco-points to the fossil fuel category, 3,93e^{+06} to the climate change, and approximately 3,15e^{+06} to the respiratory inorganics, and 2,70e^{+06} to the carcinogens. The impact categories mainly affected by the nuclear source are valued in land use at 1,26e^{+06} eco-points and radiation at 4,05e^{+05} eco-point. It is clear that the source of energy generation will be reflected in the impact categories affected. Moreover, the balance in between sources will also affect the percentile contribution to the eco-point valuation.

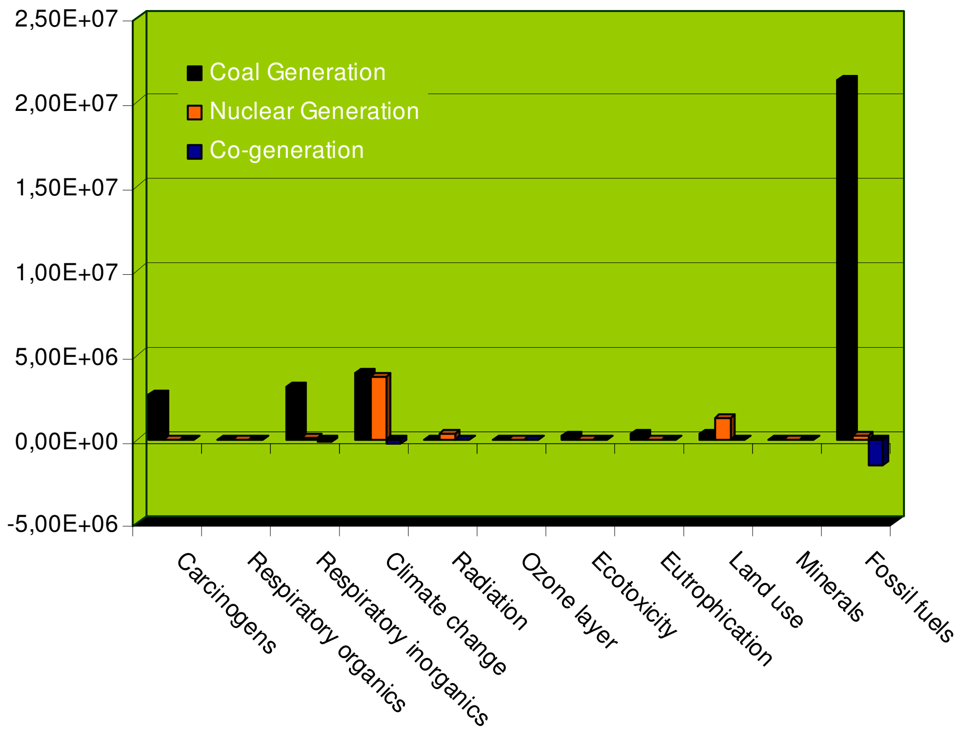


Figure 13. Cartuja Electricity Impact Categories Business as Usual Strategy

k. Impacts of Wastewater Treatment Business As Usual Strategy

The environmental impacts for the two wastewater treatment plants (Cartuja & Almozara) are measured in eco-points. The major impact category for Cartuja & Almozara WWTP's in the model is the Ecotoxicity. This result is due to the sludge material content in heavy metals, which are inputs in the form of emissions to soil. In terms of plant contributions, Cartuja represents 98% of the total impact with1,30E^{+07} eco-points for ecotoxicity and 3,15E^{+05} in carcinogens. Again as in the Base Case, the higher percentage for Cartuja's impact can be attributed to the larger loads of wastewater treated, now increasing its population coverage by 30%, versus the population coverage for Almozara remaining the same due to its treatment capacities.

Impact Category	Unit	Percentage	Total	Cartuja WWT	Almozara WWT
Total [Percentage]	%	100%		97,64%	2,36%
Total [Ecopoints]	Pt	100%	1,34E+07	1,30E+07	3,15E+05
Carcinogens	Pt	2%	3,15E+05	7,50E-01	3,15E+05
Respiratory organics	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Respiratory inorganics	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Climate change	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Radiation	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Ozone layer	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Ecotoxicity	Pt	98%	1,30E+07	1,30E+07	1,61E-02
Eutrophication	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Land use	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Minerals	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Fossil fuels	Pt	0%	0,00E+00	0,00E+00	0,00E+00

Table 9. Wastewater Treatment Impacts for ZUWS for Business as Usual Strategy

Figure 14. best represents the graphical representation for the negative contributions per impact category. It is clear that Cartuja has the highest impact within the WWTP proccess, contributing mainly to the ecotoxicity category by almost 98%.

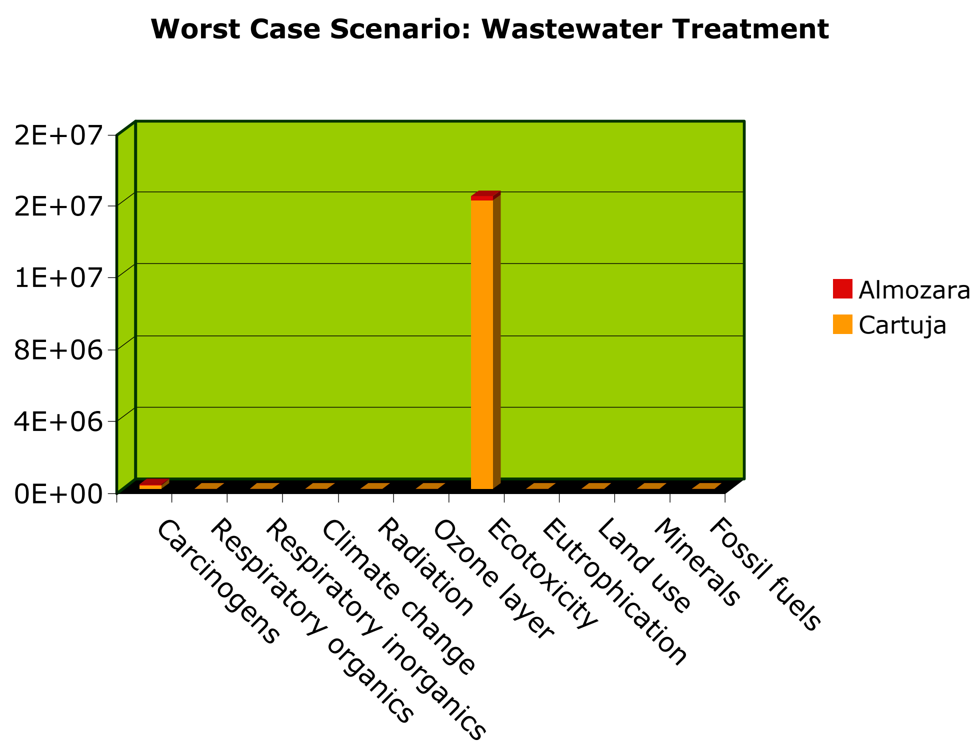


Figure 14. Wastewater Treatment Impact Categories Business as Usual Strategy

e. Expected Scenario with Action Strategy

- Population Increase to 1 Million ➔ Increased Renewable Energy Sources **(Wind +20%)**, (Coal -25%), (Nuclear -15%).

- New Water Source (Yesa Reservoir) ➔ 100% Reduction in the Chemical Input of Carbon for Pretreated Potable Water.

- Use of biosolids to replace coal fuel by 50% for Cartuja ➔ 40% Reduction of Cartuja coal contribution, and reduction of Cartuja's pollutant emissions

i. Total Impacts for Action Strategy

The assessment of the entire urban system can identify the major environmental impacts for the Action Strategy. The contribution assessment for the processes in the Zaragoza Urban Water System showed the following results:

- The WWTP's now contribute entirely to the environmental load with $1{,}16E^{+07}$ eco-points. The one impact category here is the ecotoxicity contributing 101% to the system.

- The Electricity load for Cartuja WWTP has been converted to environmental contributions through its co-generation and renewable energy practices, now positively contributing to the system by 1%, with negligible negative contributions.

Impact Category	Unit	Percent	Total	Extracted Water	Pretreated Potable	Transport Water	Cartuja Electricity	Wastewater treatment
Total [Percentage]	%	100%		0,00%	0,00%	0,00%	-1,19%	101,19%
Total [Ecopoints]	Pt	100%	1,14E+07	5,28E+00	8,45E-04	7,79E-02	-1,36E+05	1,16E+07
Carcinogens	Pt	2%	2,80E+05	3,90E-01	5,98E-05	5,88E-03	1,39E+03	2,78E+05
Respiratory organics	Pt	0%	-8,10E+01	6,17E-04	1,10E-07	8,27E-06	-8,10E+01	0,00E+00
Respiratory inorganics	Pt	0%	6,01E+03	4,64E-01	8,76E-05	6,86E-03	6,01E+03	0,00E+00
Climate change	Pt	1%	6,91E+04	1,08E+00	1,69E-04	1,67E-02	6,91E+04	0,00E+00
Radiation	Pt	0%	6,04E+03	3,55E-02	5,08E-06	3,79E-05	6,04E+03	0,00E+00
Ozone layer	Pt	0%	2,73E+01	3,42E-04	5,16E-08	1,96E-06	2,73E+01	0,00E+00
Ecotoxicity	Pt	99%	1,13E+07	4,60E-02	7,36E-06	5,82E-04	8,16E+02	1,13E+07
Eutrophication	Pt	0%	1,06E+02	4,91E-02	8,76E-06	7,30E-04	1,06E+02	0,00E+00
Land use	Pt	0%	1,78E+04	1,51E-01	2,20E-05	7,09E-04	1,78E+04	0,00E+00
Minerals	Pt	0%	7,75E+02	1,06E-02	1,69E-06	4,83E-05	7,75E+02	0,00E+00
Fossil fuels	Pt	-2%	-2,38E+05	3,06E+00	4,84E-04	4,64E-02	-2,38E+05	0,00E+00

Table 10. Total Impacts for ZUWS for Action Strategy

It is important to note at this time one of the potential deficiencies of the SimaPro model, and that is the potential for **problem shifting**. It appears most evident in the Action Strategy, that while the major impact of Cartuja Electricity negative contributions in the form of fossil fuels is eliminated, the load of the problem gets shifted to the ecotoxicity of WWTP. While the ecotoxicity issue is a sustainability problem in need of addressing, special attention should be paid that no additional loads are added to a particular impact category due to problem shifting from other categories.

Figure 15. indicates the 100% contribution of Wastewater Treatment to ecotoxicity impact category.

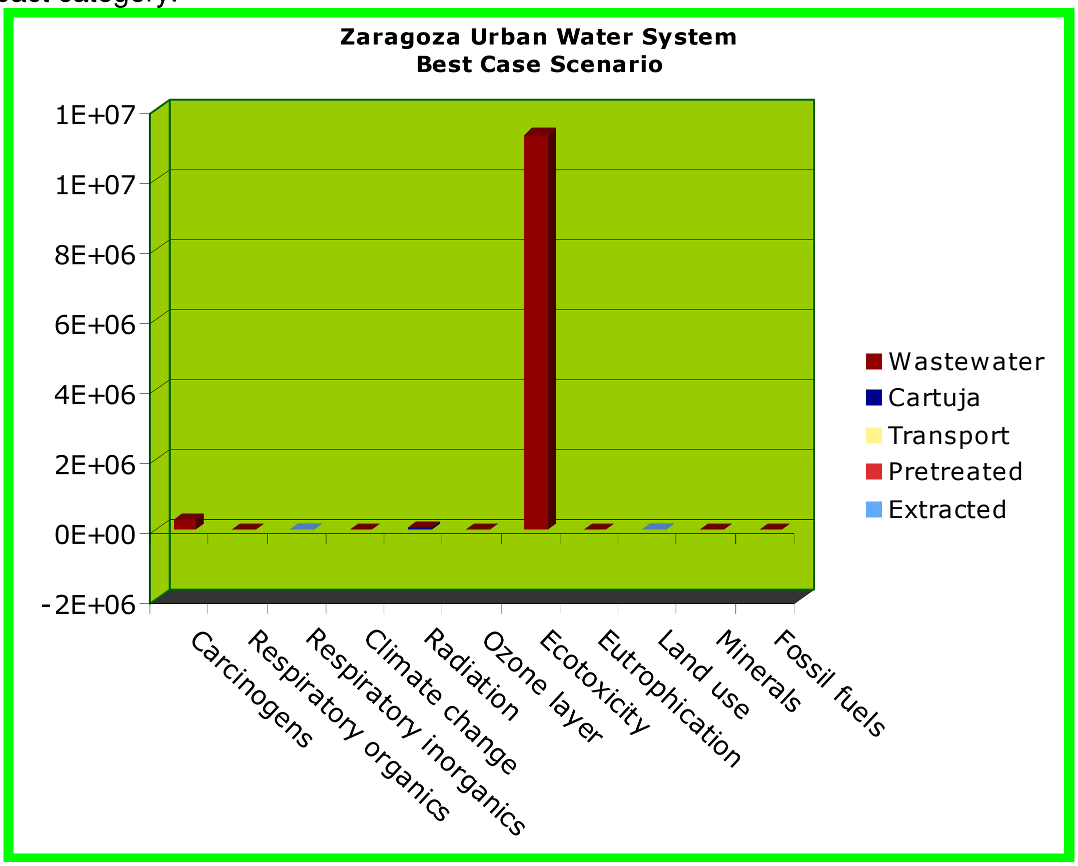


Figure 15. Total Impact Categories Action Strategy

ii. Cartuja Electricity Impacts for Action Strategy

Cartuja electricity results are measured in full eco-points. In the Action Strategy Cartuja now cogenerates 50% of its electricity, aside from implementing and increase in 20% of renewable energies. In this results the positive contribution to the Cartuja Electricity process are significant.

Cartuja Electricity has a measurable positive contribution to the ZUWS environmental load. As can be observed in the processes breakdown, coal and nuclear sources both have negative contributions of the order of 10^4 eco-points. The positive cogeneration contributions to the Cartuja system are by -2,70e^{+04} eco-points, hence reducing completely the negative environmental contribution for Cartuja.

Impact Category	Unit	Percentage	Total	Coal Generation	Nuclear Generation	Wind Generation	Cogeneration
Total [Percentage]	**%**	**100%**		**15,22%**	**84,32%**	**26,91%**	**-26,46%**
Total [Ecopoints]	**Pt/ m^3**	**100%**	**1,02E+05**	**1,55E+04**	**8,60E+04**	**2,74E+04**	**-2,70E+04**
Carcinogens	Pt/ m^3	0%	5,98E-05	1,31E-05	1,80E-05	4,34E-05	-1,47E-05
Respiratory organics	Pt/ m^3	1%	1,39E+03	-9,68E+01	-4,23E+01	-1,80E+02	1,71E+03
Respiratory inorganics	Pt/ m^3	0%	-8,10E+01	-1,99E+02	-2,38E+01	-1,98E+01	1,62E+02
Climate change	Pt/ m^3	6%	6,01E+03	2,15E+03	6,27E+03	5,90E+01	-2,47E+03
Radiation	Pt/ m^3	68%	6,91E+04	4,40E+01	6,92E+04	1,88E+02	-3,41E+02
Ozone layer	Pt/ m^3	6%	6,04E+03	8,93E+01	7,02E+03	1,47E+03	-2,53E+03
Ecotoxicity	Pt/ m^3	0%	2,73E+01	5,19E+00	3,97E+00	3,95E+01	-2,13E+01
Eutrophication	Pt/ m^3	1%	8,16E+02	1,20E+04	1,22E+03	1,10E+03	-1,35E+04
Land use	Pt/ m^3	0%	1,06E+02	3,41E-01	1,13E+02	2,43E+00	-9,40E+00
Minerals	Pt/ m^3	17%	1,78E+04	1,55E+03	2,22E+03	2,48E+04	-1,08E+04
Fossil fuels	Pt/ m^3	1%	7,75E+02	-2,79E+00	-1,22E+01	-1,53E+01	8,05E+02

Table 11. Cartuja Electricity Impacts for ZUWS for Action Strategy

Figure 16. identifies the major positive contribution to the Cartuja Electricity for Action Strategy in the fossil fuels impact category due to cogeneration activities

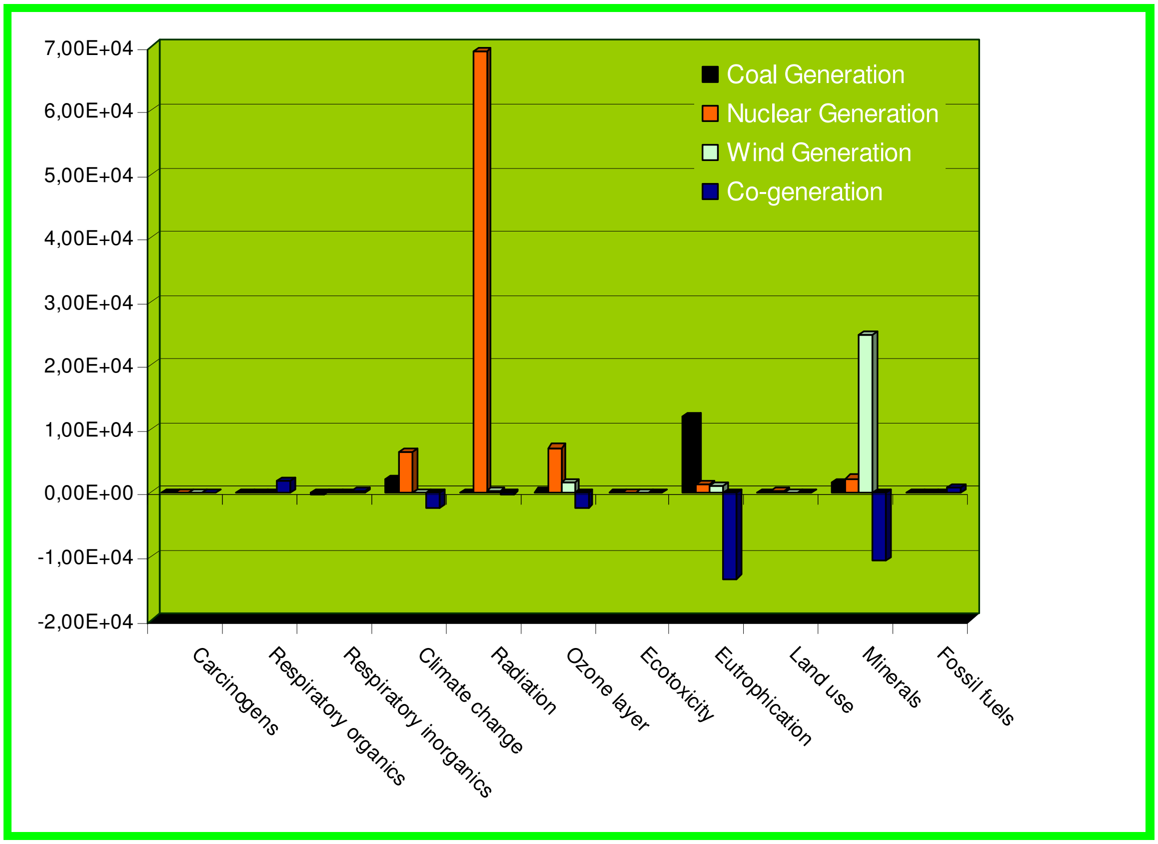


Figure 16. Cartuja Electricity Impact Categories Action Strategy

iii. Impacts of Wastewater Treatment for Action Strategy

The environmental impacts for the two wastewater treatment plants (Cartuja & Almozara) are measured in eco-points. In the Action Strategy, the major impact category for the entire ZUWS gets shifted to the ecotoxicity impact category. This result is due to the sludge material content in heavy metals, which are inputs in the form of emissions to soil. In terms of plant contributions, Cartuja represents 99% of the total impact with1,4E+07 eco-points for ecotoxicity. Again as in the Base Case, the higher percentage for Cartuja's impact can be attributed to the larger loads of wastewater treated, now increasing its population coverage by 30%, versus the population coverage for Almozara remaining the same due to its treatment capacities. The ecotoxicity contributions for Almozara are 1,9E5.

Impact Category	Unit	Percentage	Total	Cartuja WWT	Almozara WWT
Total [Percentage]	%	100%		98,61%	1,39%
Total [Ecopoints]	Pt	100%	1,16E+07	1,14E+07	1,61E+05
Carcinogens	Pt	2%	2,78E+05	2,73E+05	5,12E+03
Respiratory organics	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Respiratory inorganics	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Climate change	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Radiation	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Ozone layer	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Ecotoxicity	Pt	98%	1,13E+07	1,11E+07	1,55E+05
Eutrophication	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Land use	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Minerals	Pt	0%	0,00E+00	0,00E+00	0,00E+00
Fossil fuels	Pt	0%	0,00E+00	0,00E+00	0,00E+00

Table 12. Wastewater Treatment Impacts for ZUWS for Action Strategy

Figure 17. indicates the major ecotoxicity impact category from the Cartuja contributions

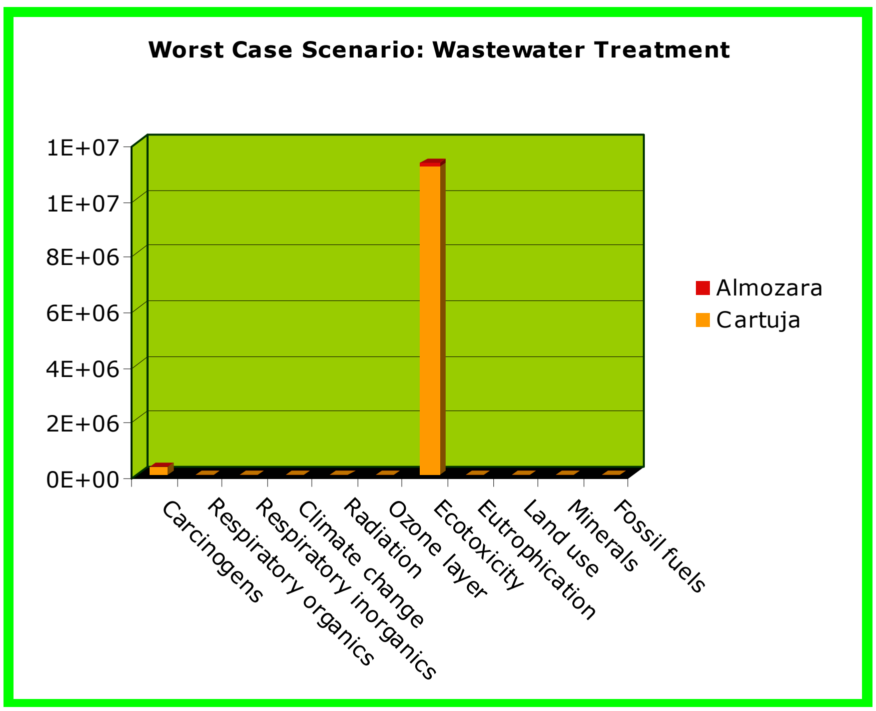


Figure 17. Wastewater Treatment Impact Categories Action Strategy

a) The Integrated Approach

a. Development of framework for environmental indicator selection

In order to follow the iterative procedure towards selecting Environmental Sustainability Indicators, a well-defined methodology shall integrate the participative aspect. The key focus of such approach is to gather the knowledge of the ZUWS and the required ESI from expert stakeholders as a way to support and compliment their final selection.

There are several steps included within this framework that will guide the process, described as follows;

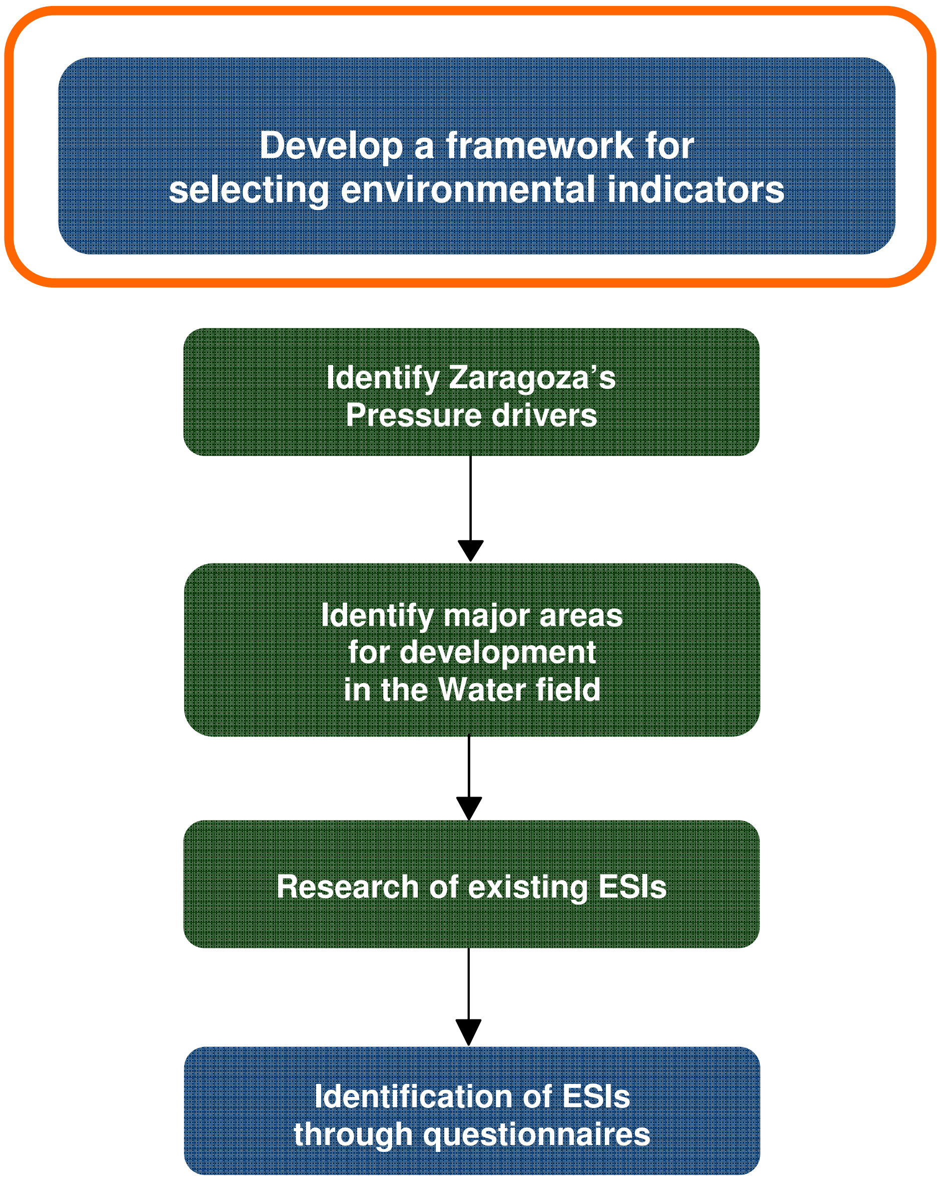


Figure 18. Framework for Developing Environmental Indicators

Steps:

1. Identify Pressure Drivers

The function of environmental sustainability indicators is both to help describe the current state, and to forecast the future sustainability of the urban water system. Therefore, it is important to understand the dynamics that affect the system by identifying Zaragoza UWS Pressure Drivers. The following drivers were identified from sources such as previous studies, Zaragoza Municipality, and newspaper articles relating to pressures in the ZUWS.

- Urbanization.
- Population increase.
- Availability of funds.
- National Politics (National Irrigation Plan).
- Climate change.
- Geographical threat of desertification & droughts.

2. Major Areas for Development

A second factor contributing to the final selection of ESI is the grouping of all aspects relevant to the water field. Such process assures that the factors need to account for include a comprehensive study with no information gaps, while at the same time allows for identification of additional issues. The grouping and their relevant questions are as follows;

2.1 **Water Resources & Supply**
- Is more water been used, than is being naturally replenished?
- Potential resources available.
- Amount of water used, and for what purposes.

2.2 **Water Pollution**
- Water quality for different uses: domestic, industrial, etc.
- Amount of water being polluted.
- Major sources of pollution.
- Potential new sources of pollution.

2.3 **Society's Response**
- Adequacy of the response system, if any.
- Measures to reduce wastewater pollution.
- Measures to reduce consumption.

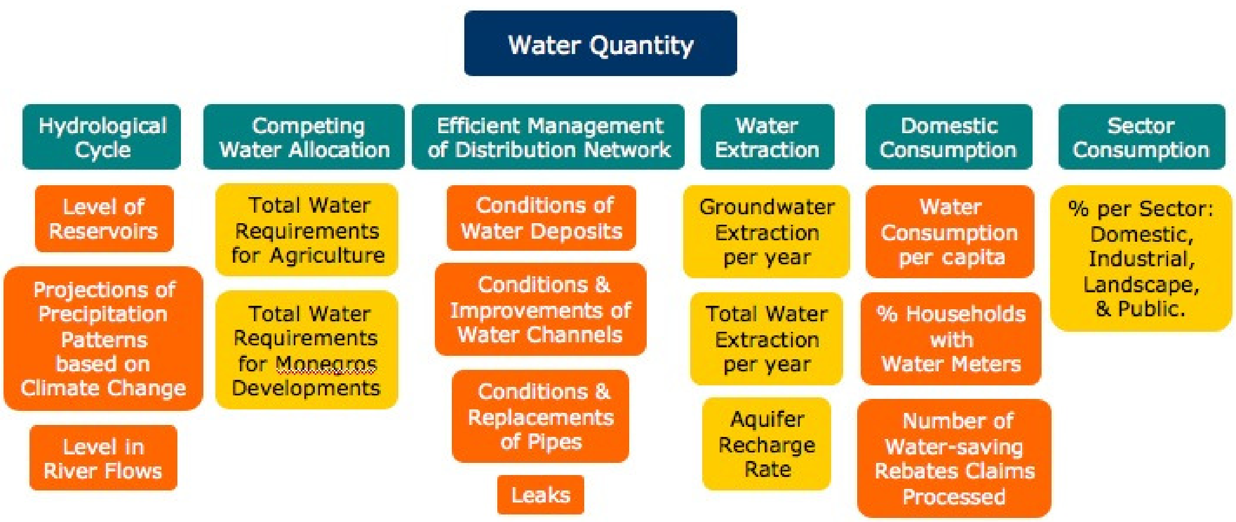
2.4 **Economic Factors**
- Adequacy of the cost-recovery system?
- Are economic factors holistic by design?
- Are social-health costs taken into account in the cost-recovery?

3. Research of existing indicators

Environmental sustainability indicators are already used in many cities, including Zaragoza. In this section, a comprehensive list of existing sources of ESI is gathered from the following sources;

3.1 European Common Indicator data.
3.2 Zaragoza Agenda 21 Indicators.
3.3 Mr. Penago's 2006 thesis.
3.4 Case studies (Lundin & Morrison, Agbar)

The gathered list of Existing Environmental Indicators can be seen in Figure 15 below. The Indicators are compiled into four sections: Water Quantity, Water Quality, Socio-Economic Aspects, and Environmental Aspects.




Water Quality
Drinking Water Quality
Health (Microbiological counts of Legionella, Micobacterium)
Benchmark Water Quality (European vs. Local Standards)
Consumer Satisfaction (Taste)
Number of municipal connections to ETAP's
Source of Water (Characterization of New Source- Yesa)
Receiving Body Water Quality (Ebro)
Stormwater Characterization (fecal,metal, phosphates)
Eutrophication (Algal blooms, nutrients in water)
Nitrates, Pesticides, Heavy Metals
Number of Municipal Connections to EDAR's
Oxygen consuming Substances (BOD, DO)
Fish population Health (Male vs. Female)
New Chemicals (pharmaceuticals)


Socio-Economic Aspects
Economic Aspect
Availability of Funds to Promote Sustainability
Money Invested on Investigation
Implementation of New Technologies (Digital Controlling Systems)
Cost-Recovery of Water in All Stages Extraction, Treatment, Distribution)
Cost of Wastewater Treatment Process
Water Rebates (Water Saving Programs)
Cost of Potabilization Process
Government Subsidies (Agriculture, Public Works)
Tariff System Based on Consumption Levels
Social Aspect
Health effects (Water Borne Disease, Cancer Outbreaks)
Public Input into Management Decisions
Cooperation with Universities for Scientific Investigations
Satisfaction Based on Potability of Water
Public Awareness & Monitoring Programs

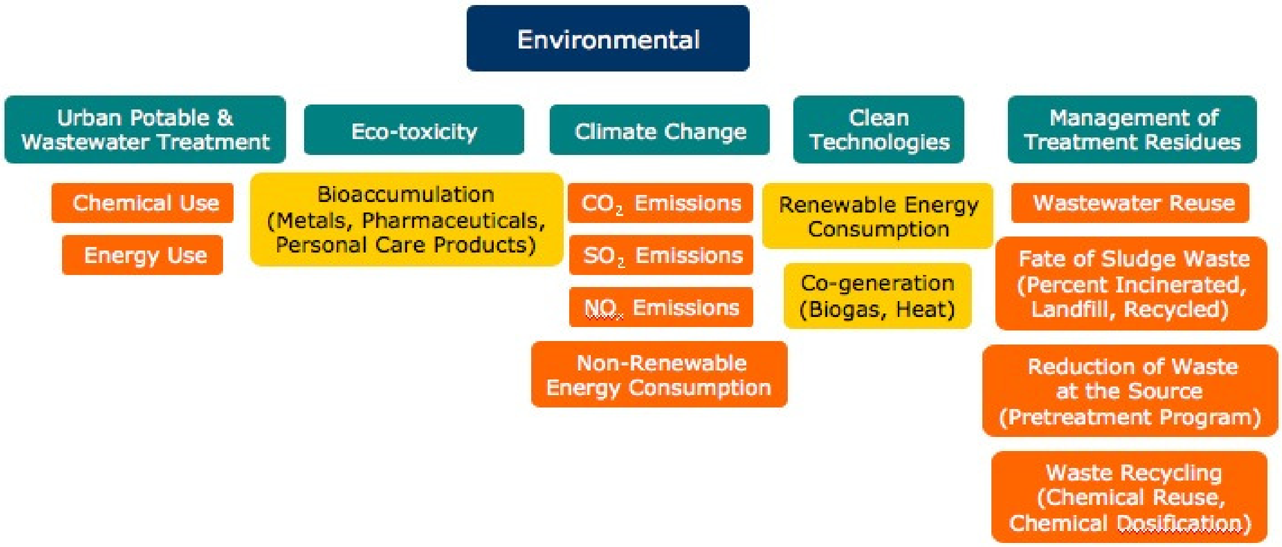


Figure 19. Existing Environmental Sustainability Indicators

Indicators as listed above are grouped into categories based on the areas for development in the water field (Quantity, Quality, Socio-Economic, Environmental). The integration of driving pressures, areas for development, and list of indicators provides for a comprehensive, well organized and clearly understood information source from which to develop questionnaires. As shown in Figure 16 below, the above procedure shall achieve integration of all relevant aspects that will lead to the sustainability of the urban water system.

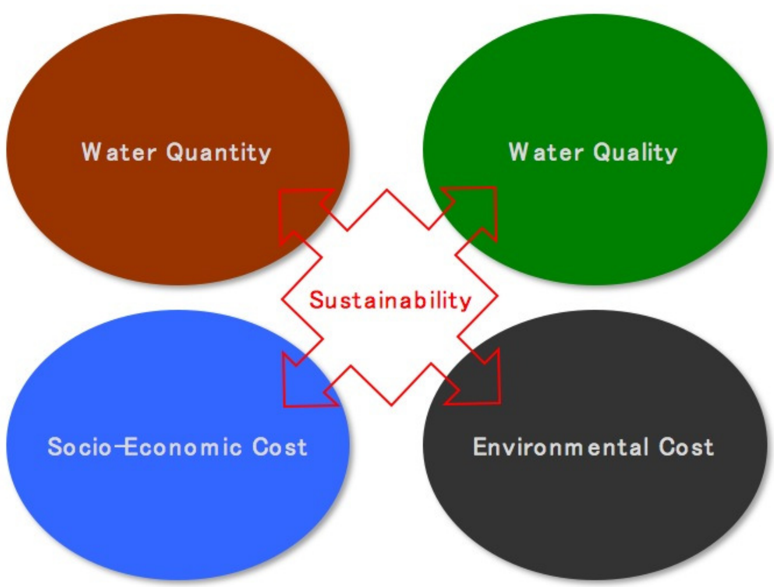


Figure 20. Environmental Sustainability Indicators Combined into Sustainability

d. Identification of Environmental Sustainability Indicators through questionnaires

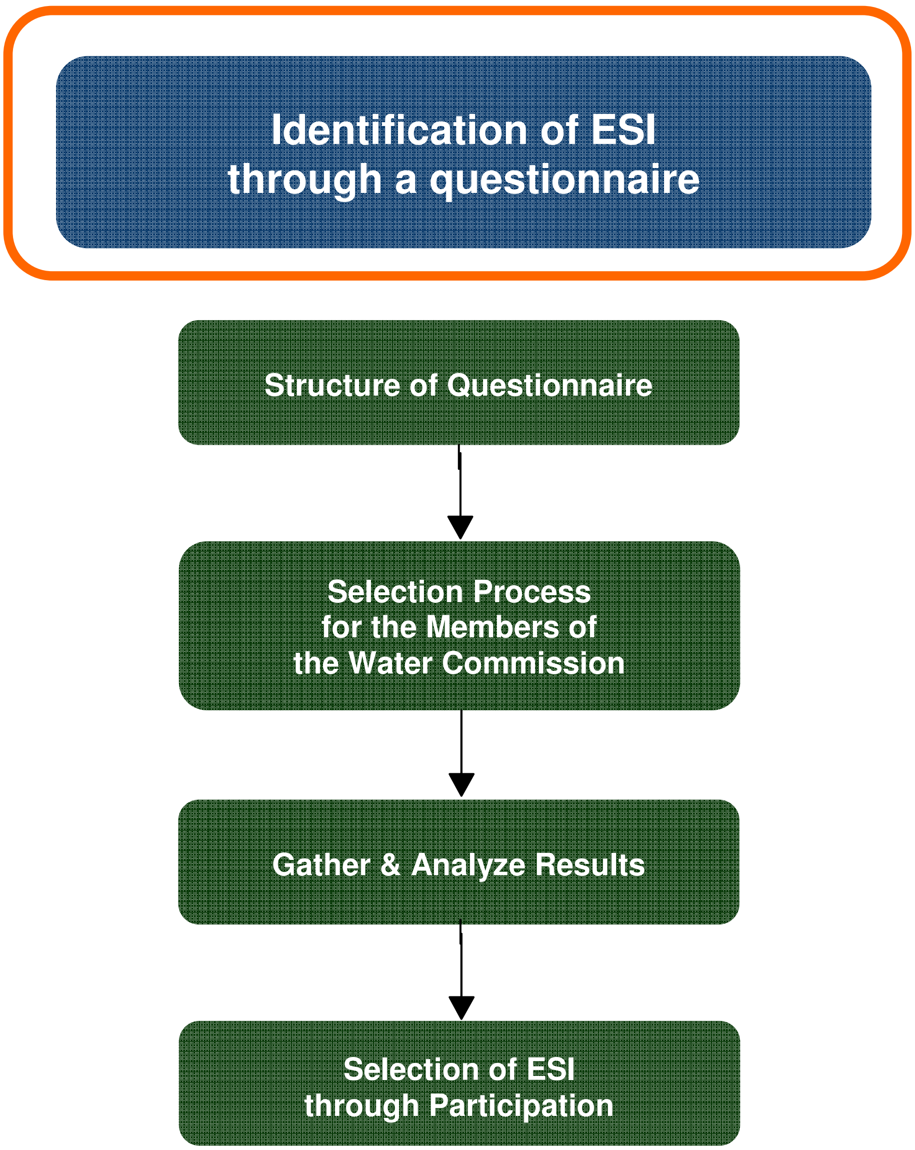


Figure 21. Selection of Environmental Sustainability Indicators Combined through Questionnaire

The final step within the framework towards the selection of ESI is through questionnaires. While a final stakeholder participation shall conclude with a workshop to get direct feedback from all stakeholders, and get an opportunity of brainstorming. Nevertheless, it is still mandatory to obtain an initial assessment of the situation, background and beliefs of the participants through the questionnaires, to be used as a starting point in the workshop.

A questionnaire offers the following advantages;

- It is practical
- There is an initial consensus on priorities (established by the questionnaire developer)
- There is flexibility to adapt to available resources
- Members understand issues, methodologies, and constraints (based on the success of the questionnaire development)

Steps

1. Structure of Questionnaire

The questionnaire took into account the following aspects;

- Objective of the Project
- Definition of Sustainability & Indicators
- Explanation of Criteria for Selection of Indicators
- Identification of Zaragoza Pressure Drivers
- Questionnaire I: Assessment of the ZUWS
- Questionnaire II: Selection of Indicators

Questionnaire I, investigates the participants perception of the current state of the Zaragoza urban water system. It consists of 16 questions in a numeric scale to rate the urban water system from Worst (1) to Excellent (5) quality of a particular characteristic of the system. The results of this questionnaire will be used to compare with the results of the SimaPro.

Questionnaire II provides with a list of indicators from which the panel can select the best, based on a previously described criteria. The results will contribute in the final selection of ESIs for Zaragoza.

2. Selection Process for the Members of the Water Commission

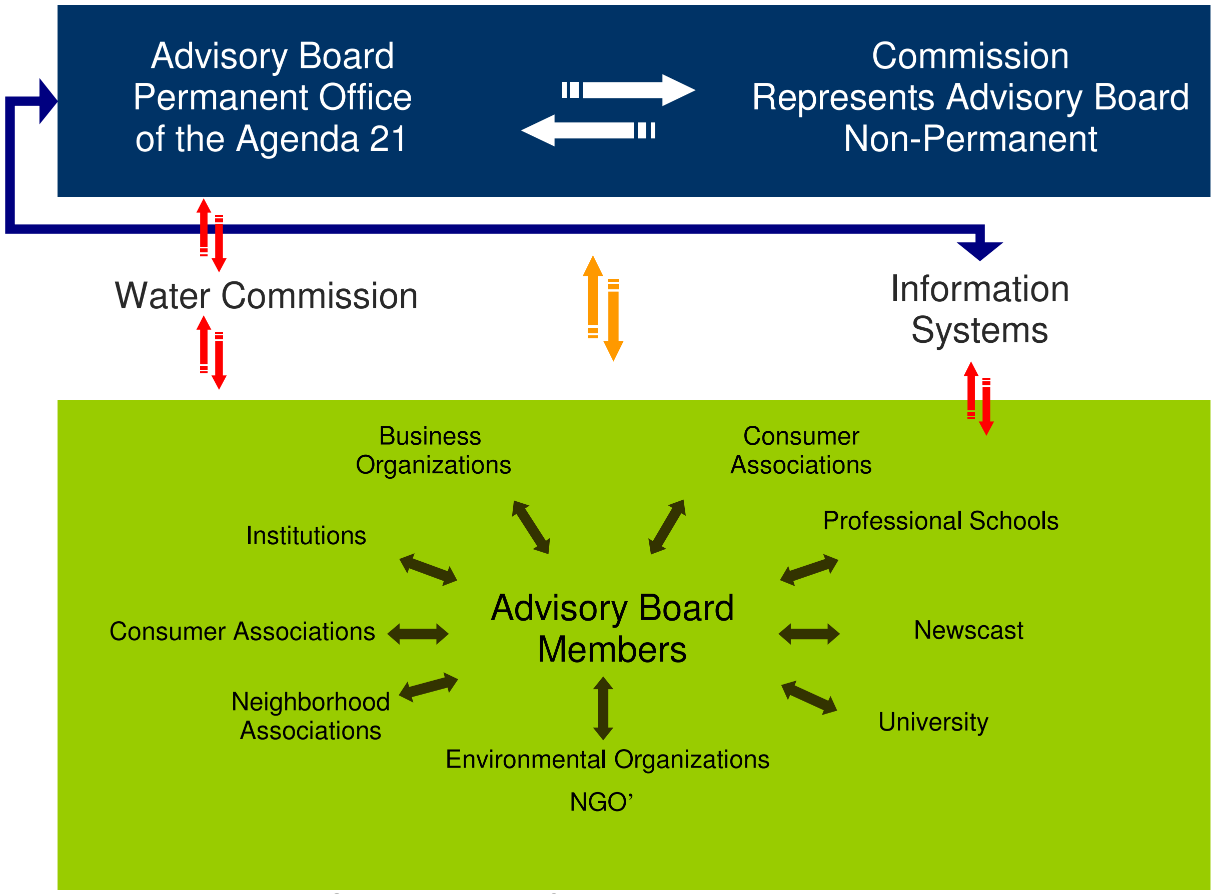


Figure 22. Structure of Water Commission Members

The above Figure 18 is a representation of the members of our selected participant's group. Following a similar pattern as the one already in use by the Agenda 21 Zaragoza, it is important to note that our representative advisory board will have a non-permanent character, meaning their members will be assembled only to participate in the current ESIs selection process. In order to select a representative participant approach, the group included at least one member from the above fields: NGO's, University, Consumer Associations, Public Institutions and so on.

The sources for the Selection of Commission Members were;

- Research Structure of Agenda 21 Commissions.
- Meet with SWITCH-Zaragoza Coordinator (Pilar Egea).
- Conduct Selection Based on Research & Expert Opinion.

3. Results of Questionnaire

Out of seventeen questionnaires sent, thirteen were returned. The results of **questionnaire I** are evaluated as follows:

The following questions were asked to the participants;

P1- What is the current situation of the Zaragoza Water Supply?

P2- What are the prospects for the future of the Zaragoza Water Supply?

P3- What it is the impact of human activities in the Zaragoza Water Supply?

P4- Please grade the rate of replenishment of the underground water sources.

P5- Please grade the economic incentives for the reduction of the domestic consumption

P6- Please grade the water in terms of drinking quality

P7- What percentage of the energy employed in the ZUWS is from renewable sources?

P8- Please grade the River Ebro in terms of eco-diversity

P9- Is in your opinion enough the wastewater treatment given in Zaragoza?Need to enter what each question is

P10- What it is the global impact of the industries not connected to the ZUWS?

P11- What it is the impact of human activities for the Ebro River?

P12- Is it the price of the water a true reflection of its production cost?

P13- Are the management tools available the right ones for the ZUWS?

P14- Please grade the systems of public monitoring of the ZUWS.

P15- Do you believe that public awareness has increased with regards to water?

P16- Please grade the economic incentives for the reduction of the industrial consumption

The method for answering the above questions was based on rating the conditions of the ZUWS on the following scale:

Worst	Bad	Neutral	Good	Excellent
1	2	3	4	5

The results per question to Questionnaire can be found in Annex 11.

First, the results were evaluated by multiplying the frequency of responses to its corresponding grade (1-5). Later, the responses to each question were evaluated based on the averages. The certainty of these averages is further validated based on its Standard Deviation.

The next graph serves as a compilation of the statistics related to the presented questions, where each floating-bar mass-center lies in its average, whereas its length is a representation of its standard deviation, or uncertainty.

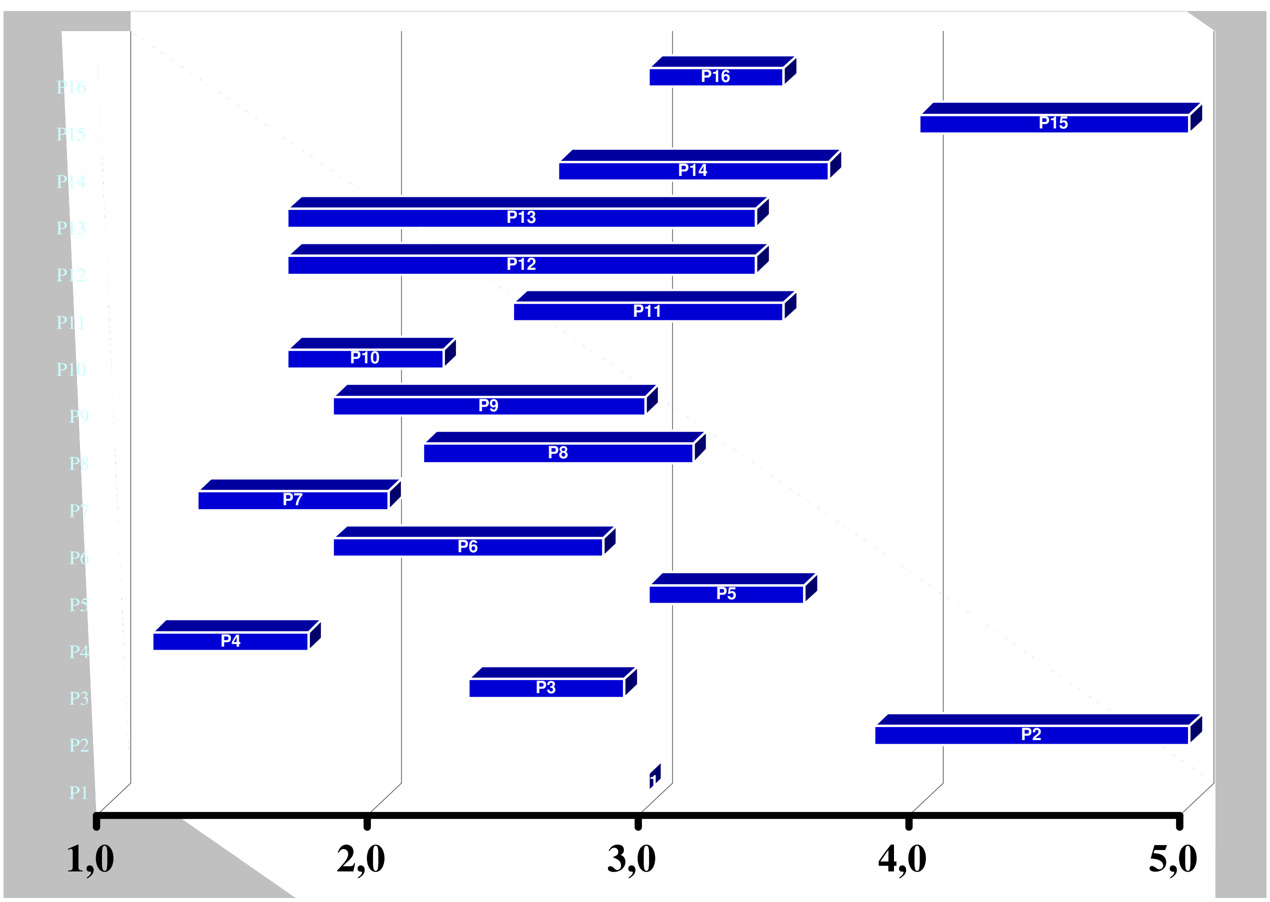


Figure 23. Statistical Representation of Results Questionnaire I

Based on the standard deviation of many of the answers, it is clear that the opinion of the participants about the current state of Zaragoza Urban Water System varies greatly from one to the other. By setting our accepted Standard Deviation to 0,6 the following questions received an average response that corresponded to the following rating;

P1- What is the current situation of the Zaragoza Water Supply?
Response: Neutral

P3- What it is the impact of human activities in the Zaragoza Water Supply?
Response: Bad

P4- Please grade the rate of replenishment of the underground water sources.
Response: Worst

P5- Please grade the economic incentives for the reduction of the domestic consumption
Response: Neutral

P10- What it is the global impact of the industries not connected to the ZUWS?
Response: Bad

P16- Please grade the economic incentives for the reduction of the industrial consumption
Response: Neutral

All the other questions had a Standard Deviation that was outside our set parameters, therefore the results can not be used to reflect a consensus on the current state of the ZUWS.

While the above results are interesting to assess the knowledge of the participants, such results would not provide sufficient information for a complete scientific study. It is for this reason that the use of the SimaPro model is a necessary tool to add a scientific foundation to the process of public participation.

The European Commission, in charge of developing the European Indices Project (European Sustainability Indicators) states that; “models are an almost indispensable tool in order to systematically analyze sustainability. However, not all essential elements lend themselves to quantitative modeling or the necessary knowledge is lacking to do so. But the assessment story can help to give model outcomes a meaning beyond the isolated indicators that are quantitatively treated”.

The scope of this thesis, due to time constrains, has been to pilot a possible assessment process, which could be extended to a wider audience in the future. The scientific model has been completed and could be used as a starting point for further refinement, while the public participation through the questionnaires themselves have been designed to be used at a larger scale in the next phase, as well as other complementary steps covered in the next section.

Results of Questionnaire II

The results of **questionnaire II** were marked as follows;

A complete list of indicators relevant to the ZUWS was presented with the following instructions;

1. Mark the useful indicators with a ……………………................................ Y
2. If the indicator list is incomplete please add.
3. Indicators not considered useful mark with a..……………..................... N
4. Finally, participants were provided with a space to make additional comments.

Results of Questionnaire

After the receipt of all the indicators collected form questionnaires, the following steps will follow:

1. Selection of indicators mentioned most frequently (>60% frequency).
2. From the previous selection list, merge indicators with a similar meaning or objective, thus reducing repetitiveness.
3. Attempt to come up with a list of only ten indicators (ideally).
4. Based on the SWITCH, "Emerging Paradigm" concept, compare & gather questionnaire indicators with those from the Sima-Pro. Finally, come up with a final selection of ESIs.

Step 1. Selection of indicators mentioned most frequently (>60% frequency)

Based on the initial indicator list provided in the questionnaire, the list results were reduced to 53% from the initial list, based on the choices of the participants. The criteria used for the elimination of indicators, was to select only those indicators selected with >60% frequency. While the remaining 47% of indicators are eliminated at this point they will be kept for future reflection on the SimaPro results.

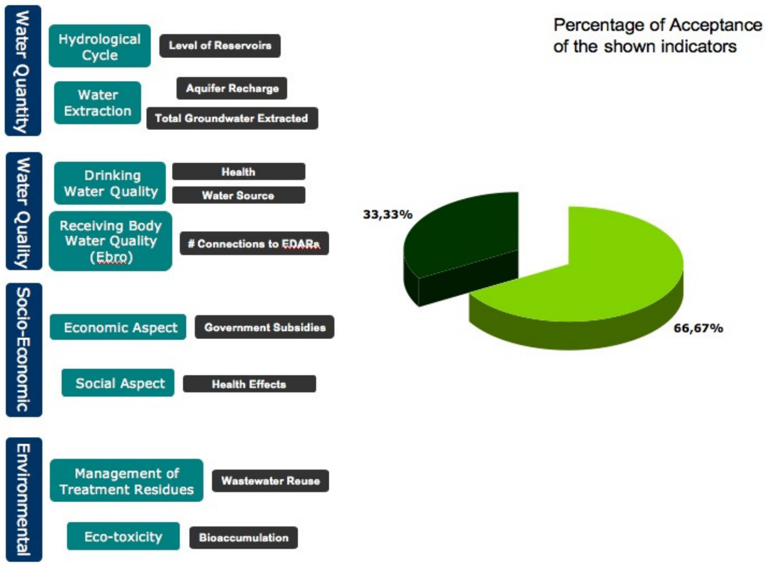


Figure 24. Indicators Selected with a 67% Frequency

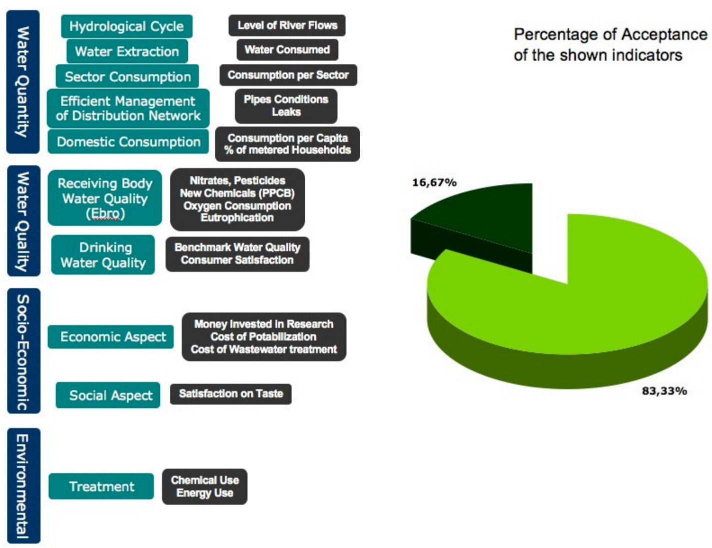


Figure 25. Indicators Selected with a 83% Frequency

Step 2. From the previous selection list, merge indicators with a similar meaning or objective, thus reducing repetitiveness

The **key objective** of this analysis is to come up with a reduced number of indicators that can most effectively measure and represent the sustainability of the system.

From the original participant selection, we are left with twenty nine chosen indicators. Based on the Bellagio Principles, a small yet concise number of

indicators are preferred. Thus, the next step is to narrow down these twenty nine indicators, to a core set of fifteen.

In the narrowing process, the indicator reduction focuses within each of the four Water Theme categories and their corresponding subcategories by reducing or eliminating grouping indicators with similar meanings. Some indicators are eliminated if other indicator exist that better represents the final end of the process. For instance, in the Drinking Water Quality category there are two indicators, namely: “Health (Microbiology; Legionella, Micobacterium)” and “Benchmark Water Quality”. In this case the “Benchmark Water Quality parameters met” indicator is found to represent both “Health” and “Benchmark Standards”, given the fact that Standards developed at European levels do take into account microbiological parameters. However, it might be possible that due to temperature vulnerability of Spain, such parameters should be stricter there. It is due to this that the final merged indicators shall be re-evaluated to best fit the Zaragoza Urban Water System. One thing to keep in mind is that this initial merging and final results of ESIs is just the beginning of a selection process from the questionnaire results. A second questionnaire shall be conducted presenting the results from the first round of Questionnaire, and a final workshop shall be conducted to agree on a consensus base of the results.

Table 13. Merging Tables of Selected Indicators per Category

Water Availability	Merging
Hydrological Cycle	
Levels of Reservoirs	Levels of River Flows
Level of River Flows	
Water Extraction	
Aquifer Recharge	Total Water consumed
Total GW Extracted	
Total Water Consumed	
Consumption per sector	
Percentage per sector	Percentage per sector
Domestic Consumption	
Per capita	Per capita
% metered households	
Management of Distribution Network	
Pipe Conditions	Pipe conditions
Leaks	

Water Quality	Merging
Drinking	
Health (Microbiology; Legionella, Micobacterium)	Benchmark Water Quality parameters met
Benchmark Water Quality	
Consumer Satisfaction	Water Source Quality Characterization
Water Source	
Receiving Water Body (Ebro)	
Nitrates, Pesticides, Heavy Metals	Existing and potential Water Quality Pollutant measurements
New Chemicals (PPCP's, hormones)	
Dissolved Oxygen	
Eutrophication	
# Connections to EDARs	

Socio-Economic	Merging
Economics	
Money Invested in Research	Government activities
Government Subsidies	
Cost of Potabilization Process	Cost recovery system
Cost of Wastewater Treatment	
Tariff System based on Consumption	
Social	
Satisfaction on taste	Epidemiological studies (Diahrrea, Gyardiasis, kidney stones, bladder cancers)
Health Effects	

Environmental
Treatment
Chemical use
Energy use
Management of Treatment Residues
Wastewater Reuse
Ecotoxicity
Bioaccumulation

Final ESIs list from questionnaire

The final fifteen Environmental Sustainability Indicators based on the questionnaire exercise are as follows;

Water Availability (five indicators)
Levels of Reservoirs.
Total water consumption.
Percentage consumption per sector (Domestic, Industrial, Public).
Domestic consumption per capita.
Pipe Conditions.

Water Quality (three indicators)
Benchmark Water Quality parameters met.
Water Source Quality Characterization.
Water Quality Measurements including new chemicals.

Socio-Economic (three indicators)
Government activities.
Cost recovery system.
Epidemiological studies (Diahrrea, Gyardiasis, kidney stones, bladder cancers).

Environmental (four indicators)
Chemical use.
Energy use.
Wastewater Reuse.
Bioaccumulation.

d. Listing of SimaPro Indicators

Sima-Pro model proved to be a useful tool to measure two key performance indicators;

- Resource use efficiency (Energy consumption, Cogeneration)
- Environmental performance (Pollutant emissions to water & air)

More specifically based on the impact categories selected from the Eco-point 99 procedure, Sima-Pro was able to measure the following indicators.

Category
Subcategory

Water Quality (one indicator)

Eutrophication

SocioEconomic Aspects (three indicators)

Health Effects

Carcinogens

Respiratory Organics & Inorganics

Ecotoxicity

Environmental (nine indicators)

Chemical use

Energy use

Clean Technologies

Cogeneration

Renewable Energy Consumption

Climate Change

Non-renewable Energy Consumption (fossil fuels)

CO_2

Ozone

Management of Residues Treatment

Reduction of waste at source

Waste recycling

In order to reduce the above list of Indicators, only those better reflecting the impact on sustainability will be selected. Such a procedure is based in the "Emerging Paradigm" concept described as follows;

The concept of "**Emerging Paradigm"**

As an innovative response system to the future pressures of urban water systems, SWITCH has developed a paradigm shift. This paradigm shift evolves from the concept of the "Old Paradigm" to the "Emerging Paradigm". The "Old Paradigm" is a response approach where water managers focus their strategies on today's current problems with no regard for the changing pressures of the future. On the other hand the "Emerging Paradigm" shifts the focus to projections

for the pressure drivers and hence the sustainability of the future urban water systems. The new paradigm combines conventional along with innovative approaches for the future. These new approaches attempt to include state-of-the-art scientific, technological, and managerial concepts.

Thus, the indicators selected based on the "Emerging Paradigm" not only take care of current needs but respond positively to the pressures of the future.

For instance:

- A reduction in chemical use shall see reductions in ➔ eutrophication, carcinogens respiratory organics & inorganics, ecotoxicity, and reduction of waste at source.

- An increase in the percentage of cogeneration & renewable energy production from the total energy consumption of the system will reflect reductions in ➔ Climate Change, energy use non-renewable energy consumption (fossil fuels), $C0_2$ emissions, ozone.

- An increase in the percentage of sludge waste recycling will reflect positive changes in ➔ General health effects, carcinogens, ecotoxicity, cogeneration, energy use, waste recycling.

Due to the technical application of the SimaPro model, the selected SimaPro Indicators are only in the Environmental category with subcategories in the Clean Technologies, and Management of Treatment Residues;

Final ESIs list from SimaPro **Category** **Subcategory**

Environmental

Chemical Inputs
Reduction in chemical use

Clean Technologies
Percentage of Cogeneration from the total energy consumption of the system
Percentage of renewable energy production from total consumption

Management of Residues Treatment
Percentage of sludge waste recycling

e. Integration of Questionnaire & SimaPro Results to develop the most appropriate "Action Strategy"

The final selection of Environmental Sustainability Indicators for this study will include the following steps;

1. Merging indicators from the **Questionnaire** and the **SimaPro** list with a similar meaning or objective, thus reducing repetitiveness.

2. Assessing the ESIs applicability to SWITCH's "Emerging Paradigm" approach.

1. Merging of Questionnaire + SimaPro Indicator List

Figure 26. Merging of SimaPro & Questionnaire List

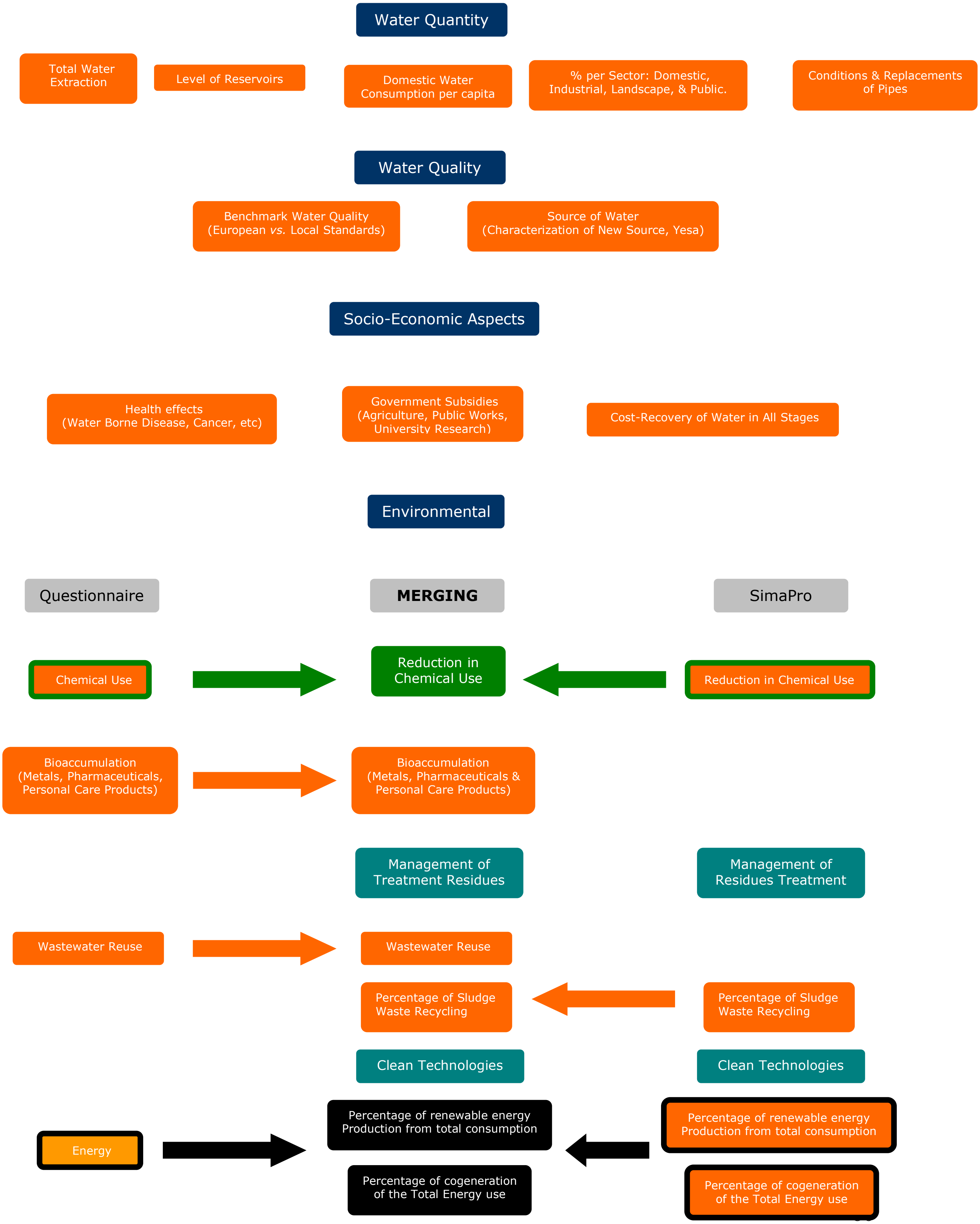


Figure 26 shows that during the merging process the water quality, water quantity, and socio-economic aspects remain the same as originally stated in the questionnaire process. The environmental category is merged from SimaPro and Questionnaire indicators with the following merging ESIs results.

- Reduction of chemical use
- Bioaccumulation (Heavy metals, Pharmaceuticals & Personal Care Products)
- Management of Treatment Residues (Wastewater Reuse, Percentage of Sludge Recycling)
- Clean Technologies (Percentage of renewable energy production from total consumption, percentage of cogeneration of total energy use)

2. Assessing that the final selection of Environmental Sustainability Indicators apply to the SWITCH “Emerging Paradigm” approach

Indicators responding to the Emerging Paradigm are;

- **Waste is a resource** ➔ Percentage of Sludge Waste recycled.
- **Reuse and reclamation** ➔ Wastewater Reuse; Percentage of cogeneration of the Total Energy use.
- **New management strategies** ➔ Introduction of renewable energies into the Energy sector.
- **Highly coordinated management** ➔ Cost recovery of Water in all Stages.
- **Collaboration=engagement** ➔ Government Subsidies to agriculture, University research for new contaminants; Pharmaceuticals, Personal Care Products.

Final criteria to consider while selecting ESIs

a) Based on the “Emerging Paradigm”, the best sustainability indicators are those that **measure positive actions** which will translate into positive environmental contributions from the system

b) Environmental Sustainability Indicators shall be **site-specific**, in other words, they shall be realistic and applicable to the city under study. ESIs need to have institutional and public buy-in in order to be successfully implemented. Due to this, the urban water system assessment and the questionnaire/ participatory phases are both essential steps towards the success of the selected ESIs.

c) Environmental Sustainability Indicators shall be **process-oriented**. Based on the SimaPro results and the integration of the "Emerging Paradigm" concept, it is clear that the most significant positive contributions from the system may be achieved by reducing the impact of those processes within the system that are most polluting. This can be done by focusing in both the regenerative energy and material cycles, as well as by reducing the material inflows.

d) As it should be expected from a modern urban water system of the industrialized world, ZUWS has sufficient infrastructure to provide basic potable and sanitation services. In such cases sustainability should be best addressed by improving the already modern infrastructure with **state-of-the-art technologies**, to further address difficult pollutants such as heavy metal removal, or to detect new pollutants such as PPCP's.

e) Implementation of ESIs must not only be applicable but also they should be **"achievable"**, taking into account both implementation and monitoring costs, efficiency, and benefits to the city. For example, electrokinetic is an effective process targeting the removal of heavy metals from waste sludge, but it comes at a high price. Studies for the sustainability of state-of-the-art technologies shall also take into account **economic feasibility, and energy efficiency** as well.

Discussion:

The Zaragoza System fits under the type of **conventional, large-scale urban system** typical of an industrialized city. Such a system covers the basic health and safety objectives for water quality, and counts with an efficient purification system to remove pollutants. As any developed countries, the main sustainability challenges facing the ZUWS are based in the future challenges commonly found in the pressure drivers such as population and urbanization growth, and climate change.

Zaragoza has demonstrated to be a demo city for the implementation of **sustainable practices**, with its water saving activities, the development of the World Water Expo 2008, and the desire to become a SWITCH-pilot city.

In this study, the use of a **model** proved an effective way to start the sustainability assessment process, by adding effectiveness and accessibility to an otherwise possible abstract discussion. The modeling phase improved the ability to define the scope of the final results based on the model's outputs.

Life Cycle Analysis (LCA) proved a good methodology to demonstrate the environmental burdens of the ZUWS and hence as a good tool for the sustainability assessment of the city. The tool for creating alternative scenarios to rate sustainability proved helpful based on interpretation from the networks. The table results and the measurements in eco-points are more difficult to interpret, especially if these results were to be presented to non-technically oriented decision makers. On the other hand the graphical network representation of the impacts proves to be easier to interpret and therefore will be a helpful presentation tool for wider audiences with no technical background.

The general results for the ZUWS model were those expected from an industrialized city and matching up to the previous literature review discussions. The major impacts to the ZUWS were;

- Energy consumption
- Sludge Management
- Wastewater Treatment Plants

The conclusions to resolve the sustainability issues affecting the ZUWS included;

- Energy efficiency, Cogeneration, and Renewable technologies
- Optimization of WWTP design
- Better management of WWTP
- Pollutant prevention at the source

The environmental burdens of a system can be further shifted to environmental contributions if the "Emerging Paradigm" is applied to the selected ESIs.

An important aspect learned from the stakeholder participation approach, is that sustainability is a local process. If a sustainability strategy is designed by the stakeholders within the targeted city, it is more likely to be socially accepted and therefore implemented.

Limitations:

SimaPro does not account for water volumes within the system, hence water consumption, and water losses are neglected aspects to evaluate towards the sustainability. Such factor is very important towards the evaluation of the urban sustainabiliy. Complementary information shall be added to further rate the system with regards to water volumes.

Eco-indicator 99 has limitations in the nutrient emissions to the water, in the eutrophication factor. Therefore an adaptation to the Eco-indicator must be made to include such factor.

Significant improvements could be made in the SimaPro user interface aspects, to facilitate situations such as having more than one project opened at once. Further improvements could be also made in the waste scenario sections of SimaPro.

Recommendations for future research:

A more detailed study on the economic and social cost to the ZUWS

A detailed study conducted on the sustainability of state-of-the-art technologies to address Wastewater Treatment Plant's Ecotoxicity issues. Such a study shall pay special attention to the economic, and energy cost to the Zaragoza Urban Water System, in order to truly rate its sustainability.

A comparative of the ZUWS to other SWITCH pilot cities, for example Alexandria, to come up with common sustainability criteria, that is yet adaptive to every case scenario

The further integration of the SimaPro model or any other application (such as Excel) as a tool to measure the water balance in an Urban Water System

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Annexes

Datos EDAR 2007

EDAR ALMOZARA

Id	FECHA	CAUDAL (m3)	ENERGIA_MOTOGEN(Kwh)	ENERGIA_ENDESA(Kwh)	ENERGIA_TOTAL(Kwh)
1	ene-07	693.402	166.000	44.421	210.421
2	feb-07	637.493	110.400	69.194	179.594
3	mar-07	725.068	156.100	47.093	203.193
4	abr-07	808.275	97.400	47.647	145.047
5	may-07	1.088.421	133.400	52.208	185.608
6	jun-07	997.910	149.500	50.523	200.023
7	jul-07	924.070	138.800	41.469	180.269
8	ago-07	902.000	116.300	81.118	197.418
9	sep-07	973.748	144.200	45.316	189.516
10	oct-07	927.569	132.200	62.849	195.049
11	nov-07	826.228	154.800	42.358	197.158
12	dic-07	892.461	131.700	74.874	206.574
	Totales:	10.396.645	**1.630.800**	659.070	2.289.870
	V.Medio:	866.387,08	135.900,00	54.922,50	190.822,50
	%		0,71	0,29	
	Nº meses:	12	12	12	12

EDAR CARTUJA

Fecha	CAUDAL (m3)	Kwh_EDAR	Kwh Turbina	Kwh Totales
Enero	4.677.900	2.742.600		2.742.600
Febrero	3.872.700	2.242.300		2.242.300
Marzo	3.811.300	2.454.000		2.454.000
Abril	3.290.800	2.241.300		2.241.300
Mayo	4.415.700	2.432.300	89.000	2.521.300
Junio	4.602.600	2.296.500	375.300	2.671.800
Julio	4.512.800	2.376.800	320.600	2.697.400
Agosto	4.143.600	2.059.800	292.000	2.351.800
Septiembre	4.587.900	2.088.800	394.100	2.482.900
Octubre	4.738.500	2.233.400	430.400	2.663.800
Noviembre	4.095.400	2.130.300	420.900	2.551.200
Diciembre	4.783.700	2.360.300	355.100	2.715.400
Totales:	51.532.900	**27.658.400**	**2.677.400**	**30.335.800**
Medias:	4.294.408	2.304.866,67	334.675,00	2.527.983,33

Annex 1

	Rain (m)	Impervious area (m^2)	Rain*imp. Area (m^3)	Volume (litres)	TSS (ton)	Unit load (kg/ha)	BOD (ton)	COD (ton)	Total N(ton)	Total P(ton)
ener-06	0,016	28000000	448000	448085120	85	3,04058E-07	5	38	14	0,15
febr-06	0,027	28000000	756000	756143640	144	5,13097E-07	8	64	24	0,26
marz-06	0,013	28000000	364000	364069160	69	2,47047E-07	4	31	12	0,12
abri-06	0,026	28000000	728000	728138320	138	4,94094E-07	8	62	23	0,25
may-06	0,016	28000000	448000	448085120	85	3,04058E-07	5	38	14	0,15
juni-06	0,041	28000000	1148000	1148218120	218	7,79148E-07	13	98	37	0,39
juli-06	0,038	28000000	1064000	1064202160	202	7,22137E-07	12	90	34	0,36
agos-06	0,006	28000000	168000	168031920	32	1,14022E-07	2	14	5	0,06
sept-06	0,061	28000000	1708000	1708324520	325	1,15922E-06	19	145	55	0,58
octu-06	0,025	28000000	700000	700133000	133	4,7509E-07	8	60	22	0,24
novi-06	0,043	28000000	1204000	1204228760	229	8,17155E-07	13	102	39	0,41
dici-06	0	28000000	0	0	0	0	0	0	0	0,00
2006				8737659840	1660	5,92913E-06	96	743	280	3

Annex 2

	Canal	Ebro	ACESA	CAPTADA	Recuperada	TRATADA TOTAL
ener-07	5.002.555	322.937	0	5.325.492	246.429	5.571.921
febr-07	879.094	4.165.712	0	5.044.806	306.669	5.351.475
marz-07	5.315.694	0	0	5.315.694	424.207	5.739.901
abri-07	4.791.220	0	101.513	4.892.733	441.068	5.333.801
mayo-07	5.365.006	0	0	5.365.006	441.105	5.806.111
juni-07	5.519.676	0	0	5.519.676	489.805	6.009.481
juli-07	5.757.774	0	0	5.757.774	508.349	6.266.123
agos-07	5.272.558	0	15.825	5.288.383	393.113	5.681.496
sept-07	5.366.180	0	0	5.366.180	411.055	5.777.235
octu-07	3.686.838	1.154.729	498.205	5.339.772	335.668	5.675.440
novi-07	1.108.643	3.297.949	859.203	5.265.795	306.779	5.572.574
dici-07	5.545.503	0	0	5.545.503	353.607	5.899.110
ANUAL	**53.610.741**	**8.941.327**	**1.474.746**	**64.026.814**	**4.657.854**	**68.684.668**

C O N S U M O S

	HIPOCLO KGRS	SULFATO KGRS	POLI KGRS	ENERGIA KW-H
ener-07	**154.480**	**179.480**		**541.818**
febr-07	**127.560**	**277.360**		**403.636**
marz-07	**178.980**	**443.030**		**500.147**
abri-07	**156.040**	**634.020**		**451.305**
mayo-07	**204.000**	**823.470**		**492.828**
juni-07	**301.340**	**330.720**		**507.592**
juli-07	**305.460**	**405.700**		**516.608**
agos-07	**231.560**	**356.060**		**476.169**
sept-07	**199.120**	**358.260**		**476.767**
octu-07	**180.640**	**487.000**		**475.274**
novi-07	**76.780**	**435.180**		**482.291**
dici-07	**154.000**	**357.450**		**492.041**
ANUAL	**2.269.960**	**5.087.730**	**1.200**	**5.816.476**

Water Pumped (l/year)	21681000000
Water Pumped (T/year)	**21681000**
Aljibes (number)	7500
Floors	6
Flats per Floor	4
People per Flat	3
Consumption (l/day)	110
Water Density (Kg/l)	1
Avg Height (floors)	3
Avg Height (meters)	9,75
Potential Energy (Joules/day)	5675670000
Potential Energy (Joules/year)	2,07162E+12
Potential Energy (kwh/year)	74578,30374
Pump Efficiency (%)	30%
Total (kwh/year)	**248594**

CO2 Emissions Factors

	Sources %	Base Case			
		Almozara		Cartuja	
		Power [kw]	CO_2 [Tons]	Power [kw]	CO_2 [Tons]
CHP		1,779,120	0	2,677,400	0
Coal	**70%**	441,357	432.53	19,360,880	18973.66
Nuclear	**30%**	189,156	3.78	8,297,520	165.95
Wind	**0%**	0	0.00	0	0.00
		630,513	**436**	**27,658,400**	**19140**

	Sources %	Worst Case Scenario			
		Almozara		Cartuja	
		Power [kw]	CO_2 [Tons]	Power [kw]	CO_2 [Tons]
CHP		2,312,856	0	3,480,620	0
Coal	**70%**	1,618,999	1586.62	25,169,144	24665.76
Nuclear	**30%**	485,700	9.71	10,786,776	215.74
Wind	**0%**	0	0.00	0	0.00
		2,104,699	**1596**	**35,955,920**	**24881**

	Sources %	Best Case Scenario			
		Almozara		Cartuja	
		Power [kw]	CO_2 [Tons]	Power [kw]	CO_2 [Tons]
CHP		2,312,856	0	16,065,192	0
Coal	**60%**	1,618,999	1586.62	14,022,809	13742.35
Nuclear	**20%**	485,700	9.71	4,674,270	93.49
Wind	**20%**	0	0.00	4,674,270	0.00
		2,104,699	**1596**	**23,371,348**	**13836**

Impacts of Water Treatment

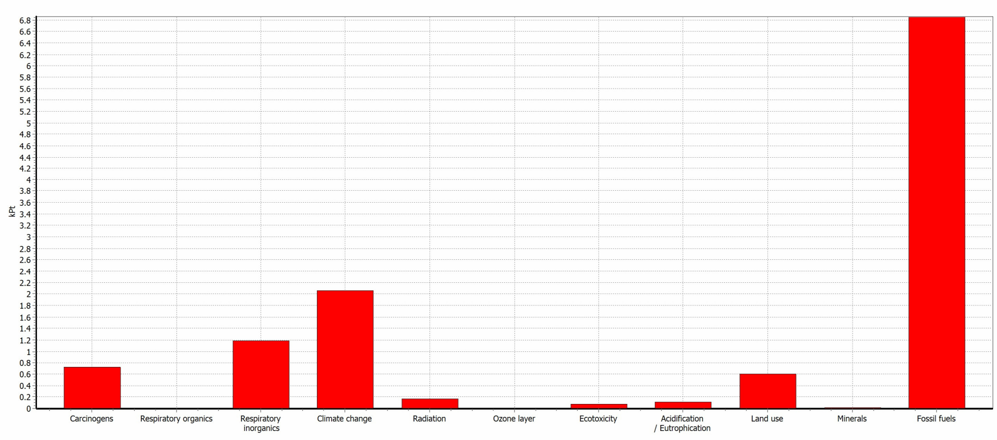
Impact Category	Unit	Percentage	Total	Petreated Potable
Total [Percentage]	%	100%		100%
Total [Ecopoints]	Pt/ m^3	100%	1,97E-04	1,97E-04
Carcinogens	Pt/ m^3	6%	1,21E-05	1,21E-05
Respiratory organics	Pt/ m^3	0%	5,63E-08	5,63E-08
Respiratory inorganics	Pt/ m^3	10%	1,98E-05	1,98E-05
Climate change	Pt/ m^3	17%	3,43E-05	3,43E-05
Radiation	Pt/ m^3	1%	2,84E-06	2,84E-06
Ozone layer	Pt/ m^3	0%	3,91E-08	3,91E-08
Ecotoxicity	Pt/ m^3	1%	1,36E-06	1,36E-06
Eutrophication	Pt/ m^3	1%	2,00E-06	2,00E-06
Land use	Pt/ m^3	5%	1,01E-05	1,01E-05
Minerals	Pt/ m^3	0%	1,46E-07	1,46E-07
Fossil fuels	Pt/ m^3	58%	1,14E-04	1,14E-04

SimaPro 7.1 Educational
Project: Zaragoza 16/12/2007

Impact assessment

Date: 3/24/2008 Time: 11:59:05 PM

Title: Analyzing 1 p 'Pretreated Potable Water Assembly'
Method: Eco-indicator 99 (E) V2.04 / Europe EI 99 E/A
Indicator: Weighting
Per impact category: Yes
Skip categories: Never
Relative mode: Non



Analyzing 1 p 'Pretreated Potable Water Assembly'; Method: Eco-indicator 99 (E) V2.04 / Europe EI 99 E/A / weighting

Page: 1

Impacts of Water Distribution

Impact Category	Unit	Percentage	Total	Domestic Water Trans.	Industrial Water Trans.	Public Water Trans.
Total [Percentage]	**%**	**100%**		**96,98%**	**1,51%**	**1,51%**
Total [Ecopoints]	**Pt/ m³**	**100%**	**2,38E-04**	**2,31E-04**	**3,59E-06**	**3,58E-06**
Carcinogens	Pt/ m³	7%	1,71E-05	1,66E-05	2,59E-07	2,59E-07
Respiratory organics	Pt/ m³	0%	2,49E-08	2,41E-08	3,76E-10	3,76E-10
Respiratory inorganics	Pt/ m³	9%	2,05E-05	1,99E-05	3,10E-07	3,10E-07
Climate change	Pt/ m³	20%	4,81E-05	4,67E-05	7,28E-07	7,16E-07
Radiation	Pt/ m³	1%	2,75E-06	2,67E-06	4,00E-08	4,00E-08
Ozone layer	Pt/ m³	0%	1,95E-08	1,89E-08	2,86E-10	2,86E-10
Ecotoxicity	Pt/ m³	1%	1,72E-06	1,67E-06	2,61E-08	2,61E-08
Eutrophication	Pt/ m³	1%	2,17E-06	2,10E-06	3,28E-08	3,28E-08
Land use	Pt/ m³	4%	1,03E-05	9,96E-06	1,50E-07	1,50E-07
Minerals	Pt/ m³	0%	1,80E-07	1,75E-07	2,71E-09	2,71E-09
Fossil fuels	Pt/ m³	57%	1,35E-04	1,31E-04	2,04E-06	2,04E-06

SimaPro 7.1 Educational
Project: Zaragoza 16/12/2007

Impact assessment

Date: 3/24/2008 Time: 11:56:25 PM

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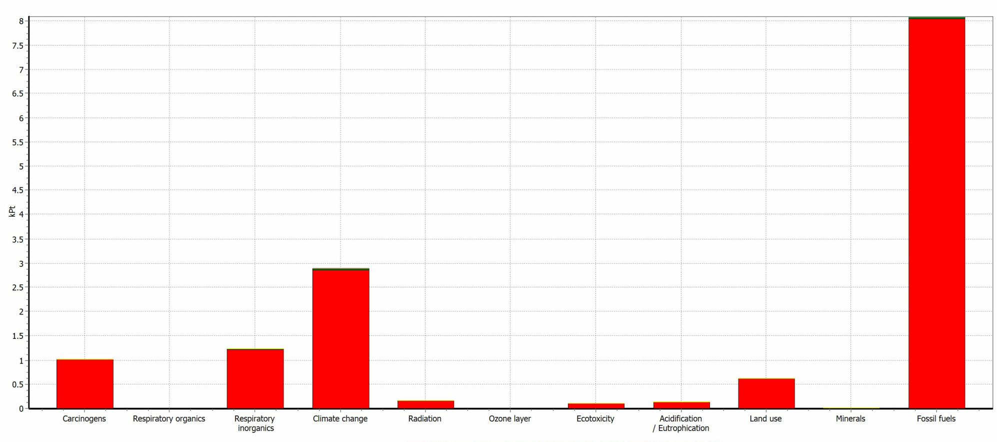
Method:	Eco-indicator 99 (E) V2.04 / Europe EI 99 E/A
Indicator:	Weighting
Per impact category:	Yes
Skip categories:	Never
Relative mode:	Non



Analyzing 1 p 'DW Transport'; Method: Eco-indicator 99 (E) V2.04 / Europe EI 99 E/A / weighting

Page: 1

Impacts of Extracted water

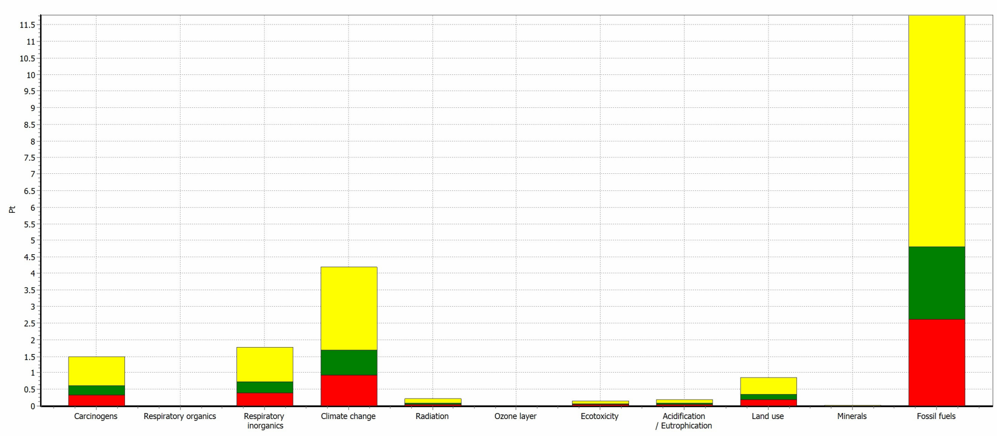
Impact Category	Unit	Percentage	Total	Extracted Groundwater	Extracted Stormwater	Extracted Surface Water
Total [Percentage]	%	100%		1,89%	96,95%	1,16%
Total [Ecopoints]	Pt/ m^3	100%	1,76E-05	3,33E-07	1,71E-05	2,05E-07
Carcinogens	Pt/ m^3	7%	1,27E-06	2,40E-08	1,23E-06	1,47E-08
Respiratory organics	Pt/ m^3	0%	1,84E-09	3,49E-11	1,78E-09	2,14E-11
Respiratory inorganics	Pt/ m^3	9%	1,52E-06	2,88E-08	1,47E-06	1,77E-08
Climate change	Pt/ m^3	20%	3,59E-06	6,65E-08	3,48E-06	4,14E-08
Radiation	Pt/ m^3	1%	1,96E-07	3,71E-09	1,90E-07	2,28E-09
Ozone layer	Pt/ m^3	0%	1,40E-09	2,66E-11	1,36E-09	1,63E-11
Ecotoxicity	Pt/ m^3	1%	1,28E-07	2,42E-09	1,24E-07	1,49E-09
Eutrophication	Pt/ m^3	1%	1,61E-07	3,05E-09	1,56E-07	1,87E-09
Land use	Pt/ m^3	4%	7,36E-07	1,40E-08	7,13E-07	8,56E-09
Minerals	Pt/ m^3	0%	1,32E-08	2,51E-10	1,28E-08	1,54E-10
Fossil fuels	Pt/ m^3	57%	1,00E-05	1,90E-07	9,70E-06	1,16E-07

SimaPro 7.1 Educational
Project: Zaragoza 16/12/2007

Impact assessment

Date: 3/25/2008 Time: 12:10:27 AM

Title:	Analyzing 1 p 'Extracted Water'
Method:	Eco-indicator 99 (E) V2.04 / Europe EI 99 E/A
Indicator:	Weighting
Per impact category:	Yes
Skip categories:	Never
Relative mode:	Non

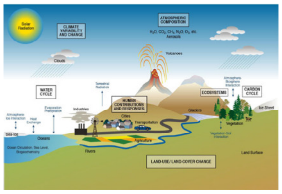


Analyzing 1 p 'Extracted Water'; Method: Eco-indicator 99 (E) V2.04 / Europe EI 99 E/A / weighting

Page: 1

Representing Groups	Members	Title	Contacto
Institutions			-
Fundacion Nueva Cultura del Agua	Laura Sanchez		Laura.fnca@unizar.es
Servicio de Gobierno de Aragon	Chechu Blasco	Head of Department	jblasco@unizar.es
Confederacion Hidrografica del Ebro (CHE)	Pablo Munilla	Hidrological Management	pablomunilla@chebro.es
Direccion Gobierno de Aragon	M. Angel Munoz	Government	mamunoz@aragon.es
Confederacion Hidrografica del Ebro (CHE)	Manuel Omedas	Sociologist	momedas@chebro.es
Grupo Analisis Economico Directiva del Agua	Lorenzo Domingo	Economist Framework Directive	at_ldomingo@mma.es
Consumer Associations			-
Torreramona Asociacion de Consumidores	Olvido Blasco	Representative	info@torreramona.org
Professional Schools			-
Quimico	M. Angel Palos	Chemist	m.a.palos@telefonica.net
Instituto de Estadistica Aragones	Julio Guiral	Statistics	jguiral@aragon.es
Servicio Investigacion Agraria	Luis Perez	Investigator- Agriculture	luisp@unizar.es
Newscast			-
Periodista Govierno de Aragon (Environmental Issues)	J. Juan Veron	Journalist-Government	jjveron@usj.es
University			-
Universidad de Zaragoza	Jorge Bielsa	Analysis Department	jbielsa@unizar.es
Universidad de Zaragoza	Ramon Barberan		barberan@unizar.es
Universidad de Zaragoza	Pedro Arrojo	Ph. D. Analysis Department	parrojo@unizar.es
Environmental Organizations/NGO's			-
Asociacion Naturalista de Aragon	Jesus Maestro Mario Izquierdo		ansar@arraquis.es
YESA Expert	Jorge Abad	Biologist	jabgar@jabadgar.e.telefonica.net
Asociacion Pesca sin Muerte	Chema Blasco	Biologist	jblasco@unizar.es
Neighborhood Associations			-
¿???????????????			
Business Organizations			
¿????????????????????			

Annex 9



Questionnaire: Recommended indicators for the Urban Water System of Zaragoza

A compiled list of researched indicators can be found below. Please carefully review the list and do the following;

1. Mark those indicators that you believe are useful ………………………….... [S]
2. Provide below your comments, if any, on the recommended indicators listed.
3. Mark those indicators that you think are not practical. ……………………….. [N]
4. Add below indicators not listed that you believe would be useful to use.

Water Quantity

Hydrological Cycle

- [S] Levels of Reservoirs
- [ ] Projections of Precipitation Patterns based on Climate Change
- [N] Levels in River Flows

Water Extraction

- [ ] Aquifer recharge rate
- [ ] Groundwater extraction per year
- [ ] Total Water Abstraction per year

Sector Consumption

- [ ] Percentage per sector (Domestic, Industrial, Landscape, & Public)

Domestic Consumption

- [ ] Water Consumption per capita
- [ ] Percent of households with water meters
- [ ] Number of water saving rebates claims processed

Cuestionario de diagnóstico sobre el estado actual del Sistema Urbano de Aguas de Zaragoza

Con el objeto de evaluar el grado de sostenibilidad del Sistema Urbano de Aguas de la ciudad de Zaragoza, se pide a los miembros de la Comisión que completen el presente cuestionario de acuerdo a sus conocimientos.

Cada pregunta se centra en algún aspecto relacionado con la gestión del suministro urbano de aguas en Zaragoza, a la que se puede responder empleando una escala numérica del 1-5, de acuerdo al siguiente esquema.

Pésima	Mala	Neutral	Buena	Excelente
1	2	3	4	5

1	2	3	4	5	
					¿Cual es la situación actual de **abastecimiento de agua** en Zaragoza?
					¿Cuáles son las perspectivas futuras de **abastecimiento de agua** en Zaragoza?
					¿Cual es el impacto de las actividades humanas en lo que afectan al **abastecimiento de agua**?
					Califique el grado de **reposición de los acuíferos** subterráneos
					Valore los incentivos económicos para la **reducción del consumo domestico**
					Evalúe el agua en términos de **calidad de consumo**

Annex 10

Annex 11

Questionnaire I Questions & Statistics

	1	2	3	4	5
P1		2	2	2	
P2		1		4	1
P3		2	2	1	
P4	2	1	1		
P5	1	2		2	1
P6	2	3	1		
P7		1	2		
P8	2	1	3		
P9	1	3		1	
P10	2	2		1	
P11	1	3		2	
P12	4	1		1	
P13	4	1		1	
P14	1	1	3	1	
P15	1			2	3
P16		1	1	2	1

Table 9. Results of Questionnaire I

						Averages	Std Dev
P1	0	4	6	8	0	**3.0**	**0.0**
P2	0	2	0	16	5	**3.8**	**1.7**
P3	0	4	6	4	0	**2.3**	**0.6**
P4	2	2	3	0	0	**1.2**	**0.6**
P5	1	4	0	8	5	**3.0**	**0.6**
P6	2	6	3	0	0	**1.8**	**1.0**
P7	0	2	6	0	0	**1.3**	**0.7**
P8	2	2	9	0	0	**2.2**	**1.0**
P9	1	6	0	4	0	**1.8**	**1.2**
P10	2	4	0	4	0	**1.7**	**0.6**
P11	1	6	0	8	0	**2.5**	**1.0**
P12	4	2	0	4	0	**1.7**	**1.7**
P13	4	2	0	4	0	**1.7**	**1.7**
P14	1	2	9	4	0	**2.7**	**1.0**
P15	1	0	0	8	15	**4.0**	**1.0**
P16	0	2	3	8	5	**3.0**	**0.5**

Table 10. Averages and Std. Deviations Results of Questionnaire I

Final SimaPro Base Case Network