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SMART WATER AND EFFICIENT MANAGEMENT IN LARGE INDUSTRIAL SITES: THE ITALIAN CASE STUDY OF ARETUSA

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Acknowledgement

I would like to take few moments to announce my heartfelt appreciation for all those without whom I would never have achieved what is at hand today. To the DICEA meticulous department body whose names still resemble kindness and will power.

Special gratitude to Dr. F. Canestrari for considering my application at the first leap of this academic journey, to Dr. G. Passerini for the unrivaled kind attitude throughout the course and ***ultimate thanks to Professor F. Fatone and the diligent team of his for such an honor of academic collaboration out of their outstanding scientific excellence and generous manners.***

With the hope to pass along the knowledge light and the goodwill warmth in turn throughout my life course.

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ABSTRACT

This study mainly focusses on the water reuse and prevention of fresh water utilization with zero liquid discharge plants through industrial symbiosis in terms of configuration and technologies. The case studies of Ultimate project and Italian case of Aretusa plant are included as practical aspect of the study which vivify the potential differences in practice with the goals and achievements in turn. For a clearer idea of the previous and present researches' status on the topic, a literature review was performed, and the most recent and relevant extracts were included as well. To provide a comparison between the presence of such approach, a Life Cycle Assessment was of the matter of essence. Two scenarios were created through the Umberto Software in order to identify the positive impact of the symbiotic relationship in place between the water utility and the chemical industry of Solvay in Aretusa case study.

1. INTRODUCTION

Water scarcity is worldly concerned as a crucial headline of internationally projected agendas which is attached to mankind life in addition to the ecosystem and climate change. The fresh water depletion is an existential threat to millions of lives and is pinned to life decency as well. Zero Liquid Dishcharge plants can safeguard a meaningful portion of fresh water from industrial utilization.

The current study has practically addressed the Industrial Symbiosis through Ultimate project and the Italian case study of Aretusa plant which serves as the circularity of water and the preventive role of water-reuse for fresh water depletion. Initially within the chapter of "State of the Art", the Ultimate Project is introduced, and the objectives are viewed in priority order. Like wisely, the Italian case study of Aretusa plant is briefly described. Proceeding to the next sub-section, the ZLD approach is presented with the most relevant and recent literary extracts related to Industrial Symbiosis, illuminating the core concept with examples and corresponding configurations.

Furthermore, the Life Cycle Assessment is discussed to quantitatively elaborate more on the practicality of the aforementioned concept of Zero Liquid Discharge plant not only in a rationale but more reliably in the analysis of environmental impacts of the status quo compared to non-symbiotic situation. Below the sub-section related to LCA, a step-by-step procedure is illustrated and supported as the software used for such analysis is concisely outlined.

Finally, through the "Result" section, both in terms of mass-flow analysis and LCIA (Life Cycle Impact Analysis) the whole scheme is put into discussion and two defined and distinguished scenarios are compared for an undisturbed understanding of the symbiotic differentiation.

2. STATE OF THE ART

2.1. ULTIMATE Project: general framework

ULTIMATE is a European-funded project which aim to serve as a trigger for "Water Smart Industrial Symbiosis" (WSIS) in which water/wastewater plays a part. As a reusable resource, but also as a vector for the extraction, treatment, recycling and storage of resources and materials. Re-used within a complex manufacturing environment that is socio-economic and market driven. Such approach that is anchored on 9 large-scale demonstrations important to agro-food in Europe and the SE Mediterranean strong chemical/petrochemical and biotech industries, production, drinks (ULTIMATE Grand Agreement, 2020).

ULTIMATE fosters and vigorously promotes corporate alliances (including industrial and technical ecosystems), water supply suppliers, regulators and policy makers by interactive Virtual Reality storytelling leveraging technology and art to co-produce common ideas for a more circular, profitable, socially conscious and environmentally safe water industry. This project draws on an incredible portfolio of past and continuing science and creativity, exploiting numerous European and global networks in order to guarantee real effects, mobilizing a broad alliance of the industrial and symbiosis cluster, leading water firms and water resources suppliers, specialists and research institutions and networking networks of water industry (ULTIMATE Grand Agreement, 2020).

2.1.1 Ultimate Project Objectives

Here in is listed top priority goals of the project with brief descriptions. The first and foremost Work Package demonstrates water-smart industrial symbiosis solutions in 9 cases across 9 different countries (8 member states and Israel), representative of key industrial sectors (agro-food, food processing, beverage, biotech, chemical and petro-chemical) and geographical settings (Western, Central and Southern Europe and SE

Mediterranean). Main objective of this WP is to evaluate the performance and demonstrate at large scale the technical feasibility of innovative technologies and symbiosis strategies. Tasks focus on demonstrating the feasibility of the proposed technologies and CE concepts in enabling the transition to more efficient symbiosis between industry and the water sector based. Specific objectives are (ULTIMATE Grand Agreement, 2020):

1. Provide long-term credible data on performance of CE technologies and symbiosis concepts
2. Derive best practice guidelines for optimized symbiosis operation
3. Highlight the synergies of symbiotic management for water reuse, nutrient & energy recovery
4. Provide data input for WP 2-6 (e.g. material and energy balances, quality of recovered products, potential microbial and chemical contamination, investment and operational cost elements)
5. Foster replication ambitions and knowledge exchange between industries, utility and technology provider on an inter-domain (water, energy, material) level and inter-case study level

The main objective of Work package number two is to assemble, further develop and demonstrate a set of transversal WSIS-support tools to identify symbiotic opportunities, improve the design and operation of symbiotic schemes and assess their medium and long-term performance within a dynamic socio-economic and business environment. The ULTIMATE tools aim to bridge the gap between technology optimization and business development. Their customization will be informed by the cases to ensure business relevance (supported by WP3) and will in turn inform and advise case development and demonstration (in collaboration with WP1). The tools include life-cycle assessment tools and risk assessment, optimization techniques, modelling and simulation tools and decision-making tools to design, assess and recommend reuse and recycling schemes based on the context and actors' interactions. Their combination will improve strategic, tactical and operational decisions for WSIS in cross-domain industries. Efforts will be devoted to make these tools and approaches as generic and transferable as possible (hence the term 'transversal') to replication to use-cases beyond the project. Specific objectives are (ULTIMATE Grand Agreement, 2020) :

1. To determine CE schemes and waste reuse/recycling strategies between industries through semantic modelling combined with optimization and simulation tools.
2. To improve future implementation of cost-efficient technology for CE guided by the industrial assessment of the processes and their optimization.
3. To link cross-domain information (water, energy, food, climate and environment) with socio-economic parameters and technology options to generate and assess the medium- and long-term performance of alternative symbiotic strategies and increase eco-efficiency and reliability.
4. To develop an online tool to guide business decisions on industry symbiosis towards maximizing benefits supported by clear KPIs, increasing the added value for the business and the region.
5. To provide an interactive platform to visualize the interactions between different stakeholders under various CE schemes to support decision makings and strategic planning.

Thirdly, the set of objectives of WP3 is to design and promote active stakeholder engagement and innovation co-creation. We draw transdisciplinary knowledge and capacities from Art, Technology and Digital Humanities. In this way, we will produce knowledge capable of addressing the complexities inherent in symbiotic arrangements engaging industry, water utilities and the general public. ULTIMATE stakeholders range from business-to-business to the general public and we need to engage both these groups in a coordinated manner, both exclusive within each of the groups and inclusive between groups. Specific objectives are (ULTIMATE Grand Agreement, 2020) :

1. Increase societal preparedness for a multitude of stakeholders from business-to business to the public.
2. Assess potential implications/societal expectations of our innovation.
3. Modelling and assessment of immersive media experiences through Place by Design in order to generate active participation, engagement and change towards WSIS.

As the fourth set of objectives, the overall goal of WP4 is to understand socio-political, regulatory and governance aspects of WSIS, to identify opportunities and challenges, and to develop innovative governance propositions to enable and encourage the development of WSIS. This WP builds on experience gained from other EU projects, such as DEMOWARE, AquaNES, NextGen and SmartPlant, which have focused on the social-political and governance aspects of water reuse, and recovery of energy, nutrients and materials from wastewater. ULTIMATE will add to that by exploring the conditions that enable or constrain the exchange of recovered water, energy and nutrients between industry sectors in the CE. Specific objectives are (ULTIMATE Grand Agreement, 2020):

1. Examine the societal expectations and challenges around WSIS and CE and analyses whether the adoption of WSIS can benefit the societal legitimization of CE and the wider relationship between industries and society (e.g. through brand identity).
2. Identify barriers and opportunities in current policy and regulation framework for WSIS applications at the ULTIMATE demo cases, including its upscaling and transferring to other geographic areas.
3. Develop innovative solutions to governance challenges and innovation support for WSIS at the ULTIMATE demo cases by suggesting adaptations to current regulations and proposing new mechanisms compatible with existing regulatory frameworks.

4. Inform regulators and industry associations on the feasibility of WSIS and offer practical recommendation for adopting WSIS in national and European governance and policy frameworks for industries.

WP5 aims to maximize impact through an ambitious action on business models and exploitation. Specific objectives are (ULTIMATE Grand Agreement, 2020):

1. Generate a short-list of 10 synergies for ULTIMATE cases, which can serve as benchmark with water-based industrial synergies developed in ULTIMATE.
2. Research thoroughly the values of water-based industrial synergies, taking into account the specificities related to water resources and develop novel business models adapted to such synergies.
3. Prepare high-impact exploitation by seeking in particular to create start-ups to commercialize the most promising project technologies and structuring a clear plan for all project technologies.

Finally, WP6 aims to achieve excellence and innovation in the communication and dissemination actions on a par with ULTIMATE technical developments, specifically:

1. Unlock and demonstrate the economic and competitive advantages of smart water management in three key industrial segments (agri/chemical/metals).
2. Profile ULTIMATE actions, actors and business models bridging the "knowing-doing" gap to inspire their peers and accelerate fellow industries into doing the same.
3. Support demo cases achieving a water smart industry, integrating industries and connection with public bodies and facilities to build 'hubs for circularity' clusters targeted in the SPIRE 2050 Vision.
4. Build public understanding and interest in industrial ecology and its contribution to sustainability.

2.1.2 Italian case study of Aretusa

The focus of this work is on the Italian Symbiotic case study of ARETUSA. This is a PPP among water utility, industry and tech provider established in Tuscany in 2001. ARETUSA replaces high-quality groundwater with treated wastewater for industrial use and uses groundwater wells for drinking water production in coastal areas. Up to 3.8 Mio. m3/y of treated municipal wastewater is already reused by the industrial partner Solvay, freeing up private industrial wells for drinking water use. The existing Wastewater Reuse Plant (WWRP) contains flocculation, sedimentation, filtration, activated carbon filter (GAC) and UV disinfection. Currently, the Solvay plant has expanded enormously both in terms of production and variety, which further increases the water demand. The plant produces sodium carbonate, sodium bicarbonate (also for pharmaceutical use), calcium chloride, chlorine, hydrochloric acid, chloromethane, plastic materials, per acetic acid and hydrogen peroxide. (ULTIMATE Grand Agreement, 2020)

In order for the effluent of Aretusa to be reusable by Solvay it's necessary to respect specific parameters reported in the table below. When Aretusa WWRP does not comply with those requirements the water is discharged in surface water bodies.

Table 1: Limit for the reuse of wastewater by Solvay

N°	Description	Unit of measure	Specific
1	Cl-	ppm	≤ 500
2	NH4	ppm	≤ 8
3	Sospended solids	ppm	≤ 2
4	Conducibility	microS.	≤1.030
5	Alkalinity	ppm CaCO3	≤ 340
6	Ca	ppm Ca	≤ 160
7	Mg	ppm	≤ 45
8	SO_4	ppm	≤ 140
9	Fe	ppm	≤ 0,1

10	Si	ppm SiO2	≤ 30
11	Mn	ppm	≤0,4
12	PO_4	ppm	≤ 3
13	Al	ppm	≤ 0,1
14	As	ppm	≤ 0,2
15	Ba	ppm	≤ 2,5
16	Fluorides	ppm F	≤ 0,1
17	Vegetable and animal oils	ppm	≤ 1
18	COD	ppm O2	≤ 10
19	Surfactants	ppm	≤ 0,5
20	BOD		≤10
21	Escherichia Coli	CFU/100ml	≤ 250
22	Coli Tot.	CFU/100ml	≤ 250
23	Strep. Coli	CFU/100ml	≤ 20
24	Filamentous bacteria		absent

2.2. Zero Liquid Discharge and Industrial Symbiosis

Zero Liquid Discharge is the approach that implies that all the Industrial Symbiosis configurations and technologies to fulfill such goal maximally. In this context a specific study was performed to analyze the themes of zero liquid discharge and industrial symbiosis which, as already explained are the main concept of the ULTIMATE Project.

Figure 1: Zero liquid discharge concept (Tong, 2016)

2.2.1 Overview

Water is one of the earth's most essential tools for regular usage in many different forms. Water capital, though, overexploitation and emissions are affected, as well as the rising market for resource-constrained water is a major challenge. This and climate change are resulting in water shortages as a result of, for example, population increase, migration to cities, and higher per capita intake of water in growing cities as well as the urban, domestic, and industrial water sectors growing establishment and intensification of industrial estates.

Figure 2: Trade-offs between the driving forces (public awareness, strict regulations and etc.) (Panagopoulos, 2020)

A more successful means of coping with these issues is a systematic and integrative research approach to water system management. It is important to understand social and environmental diversity, to include less available water supplies for management, and to explore adaptive ways to go beyond supply-side regulation. Although ZLD has a deep commitment to mitigating water emissions and increasing the availability of water, its feasibility is determined by a balance between the advantages associated with ZLD, electricity usage, and the cost of capital/operation. The drivers and advantages, that make ZLD a viable choice, are therefore crucial to consider. The implementation of new technology, such as evolving membrane-based methods, offers opportunities to reduce the energy use and costs involved and to improve ZLD's applicability (Becker, 2019)

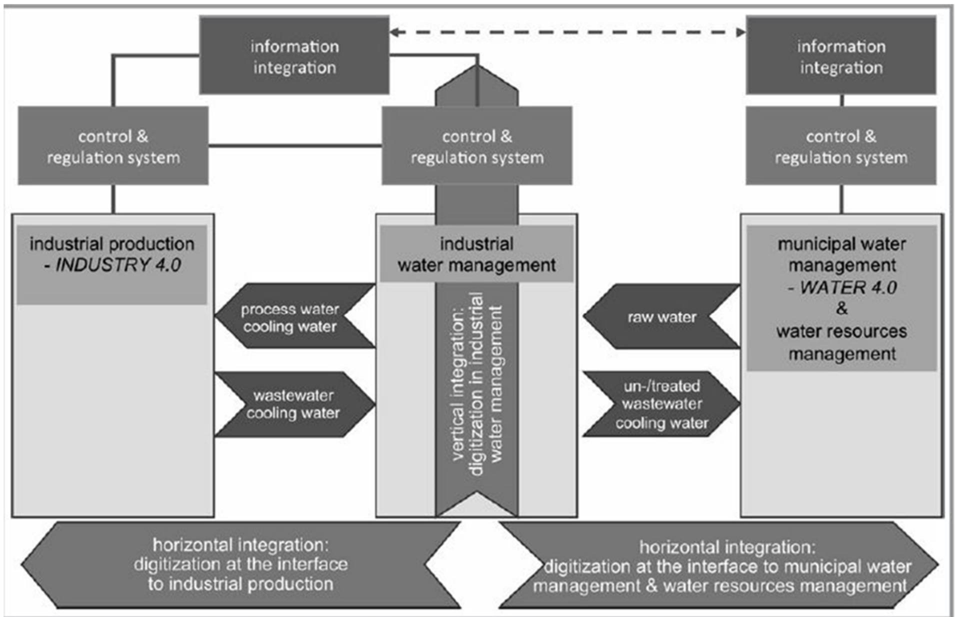


Figure 3: A schematic illustration of industrial symbiosis and its circularity (Becker, 2019)

2.2.2 Examples and considerations

Companies are expected to report a water footprint in a comparable fashion to the carbon footprint statement at present. This footprint will refer to goods, systems and organizations and will be focused on evaluations of the life cycle (LCAs). The water used would need to be quantified correctly, in a verifiable and reliable way. A new international standard, ISO14046, entitled Environmental Management: water footprint, was adopted in July 2014 to promote this (Tong, 2016).

Figure 4: Zero Liquid Discharge benefits and drivers at one glance (Tong, 2016)

As a profound example of Industrial Symbiosis found in the literature reviews is shown in the below-figures.

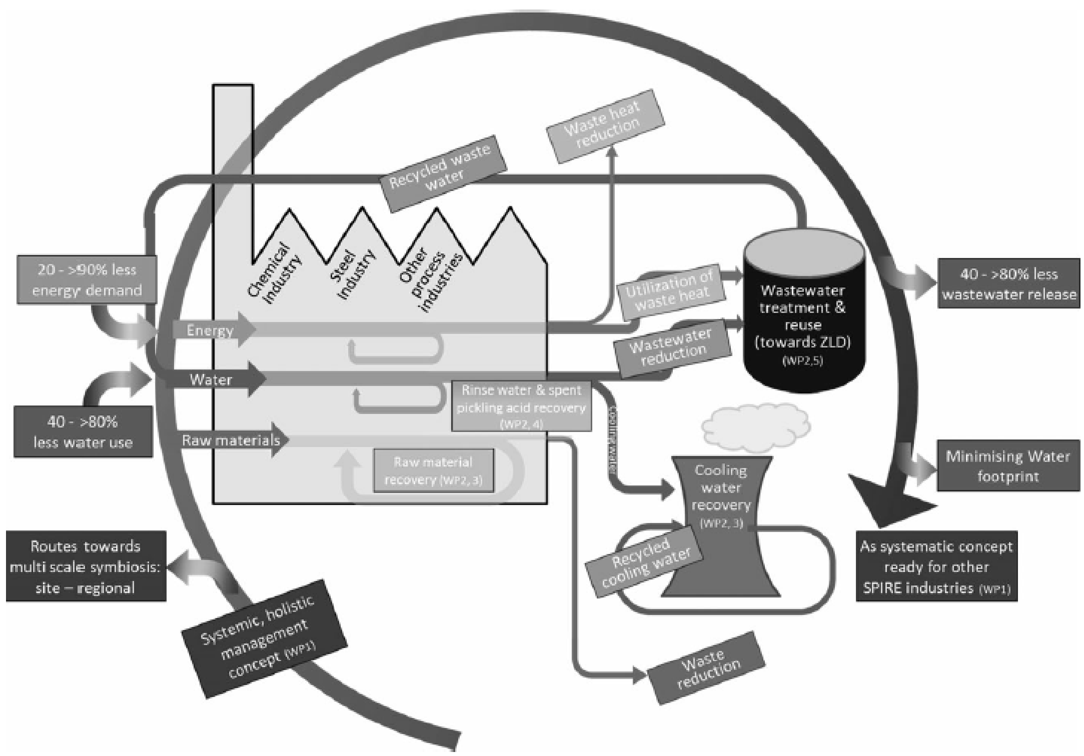


Figure 5: Zero Liquid Discharge as the closing-the-loop role (Becker, 2019)The Figure 5 illustrates the effective role of ZLD in the water fed to the industries and the sequential minimal fresh water depletion afterwards.

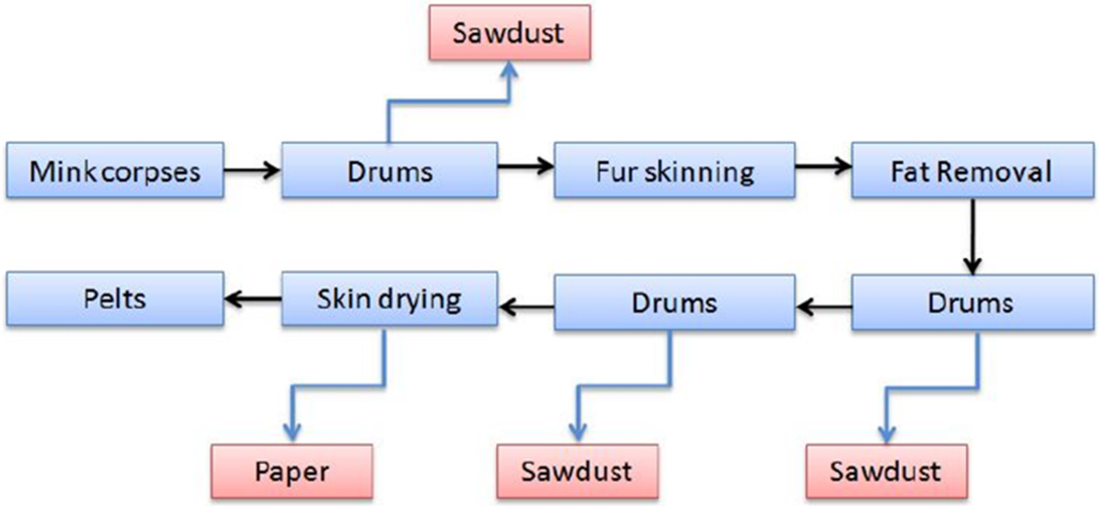


Figure 6: An Industrial Symbiosis and the beneficial linkage in between (Paper and Fur Skinning corporations) (Zamanis, 2018)

As the Figure 6 demonstrates, the Industrial Symbiosis approach implies the beneficial inter-dependency between the industries with the core goal of minimal freshwater utilization and circularity of water and energy loop.

A biogas productivity for various purposes within the maximized and beneficial within the symbiosis of industries is schematically illustrated here below.

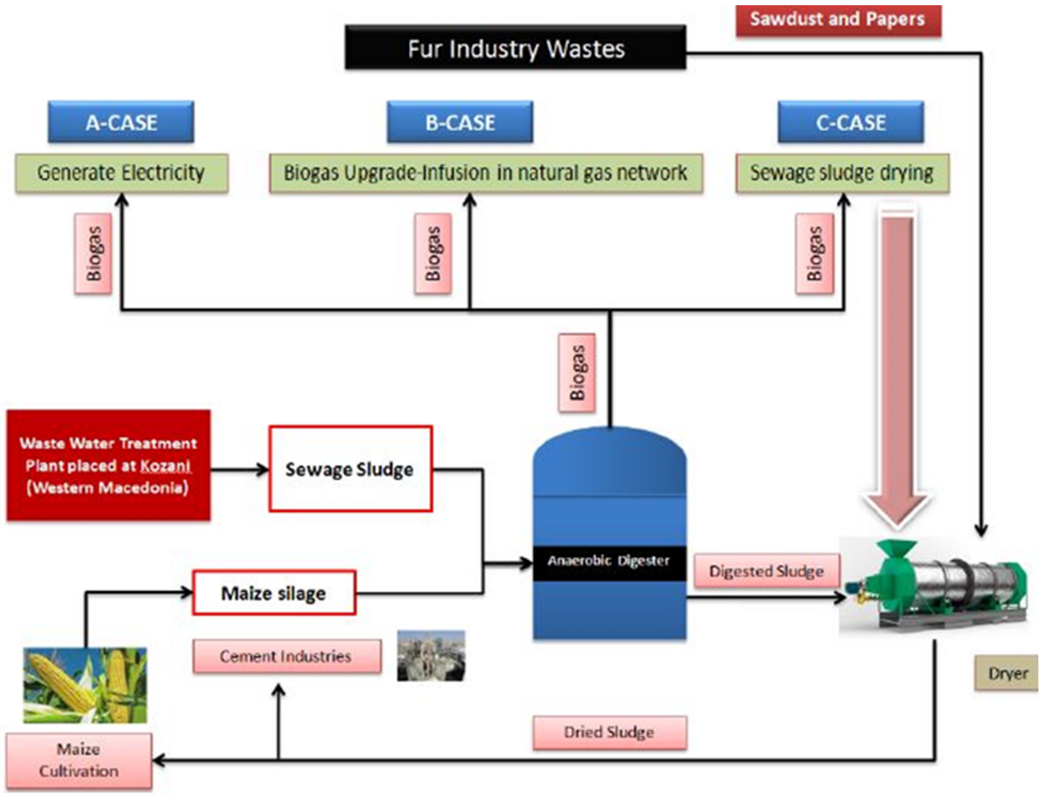


Figure 7: Industrial Symbiosis and energy production (Zamanis, 2018)

2.2.3 Technologies

Around 100% of freshwater is restored under the ZLD scheme and it creates a solid salt that can be disposed of in a more environmentally sustainable manner. In comparison to ZLD, because of lower capital costs and energy demands relative to the ZLD framework, the minimal liquid discharge (MLD) framework as recently drawn interest, as the freshwater recovery objective is up to 95 percent. Classification of pretreatment and treatment technologies in the MLD and ZLD systems are shown below (Panagopoulos, 2020).

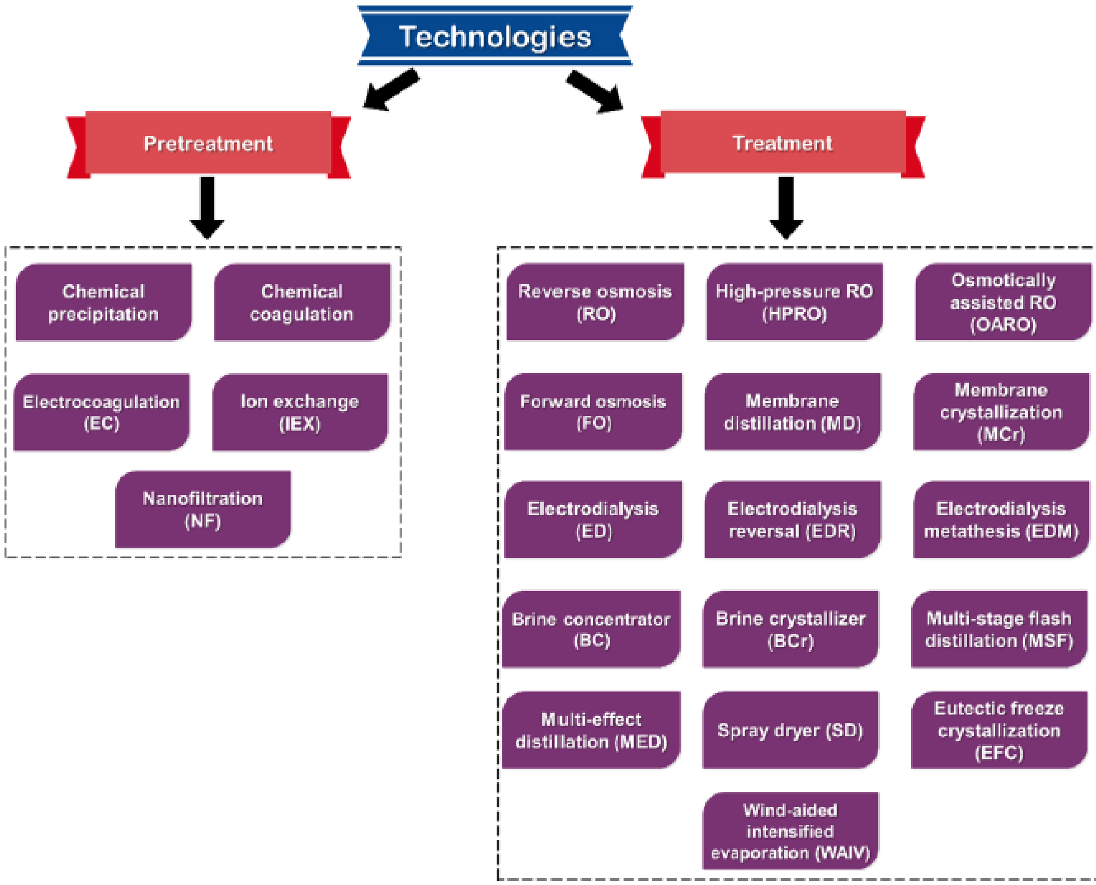


Figure 8: Technologies applied within ZLD (Panagopoulos, 2020)

The arrangement of the technologies used in the ZLD and MLD systems are shown below.

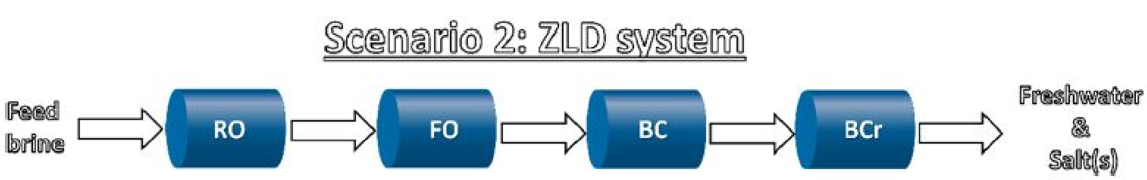


Figure 9: ZLD system sequential technologies. RO: Reverse Osmosis; FO: Forward Osmosis; BC: Brine Concentrator; BCr: Brine Crystallizer (Panagopoulos, 2020)

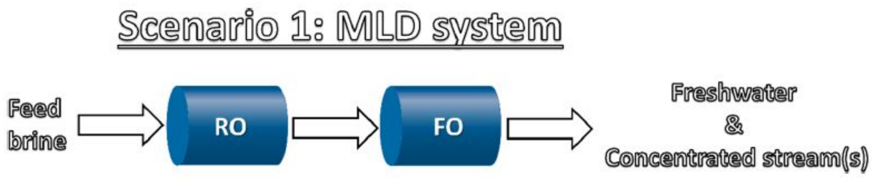


Figure 10: MLD system sequential technologies. RO: Reverse Osmosis; FO: Forward Osmosis (Panagopoulos, 2020)

Both strategies support the transition from a linear economy to a circular economy where essential commodities, such as salts, are restored, in addition to the favorable environmental effects of the two strategies. In the treatment of brine effluents, ZLD systems can be very successful (up to 100% freshwater recovery); however, their feasibility is highly restricted by high capital and operational costs.

As far as the monetary aspects are concerned, the trade-offs between both the efficiency and outcome on one side and the costs including operational and capital expenses there need to be a logical and sensible balance. Here in, a statistical relationship between the two driving factors is shown (Panagopoulos, 2020)

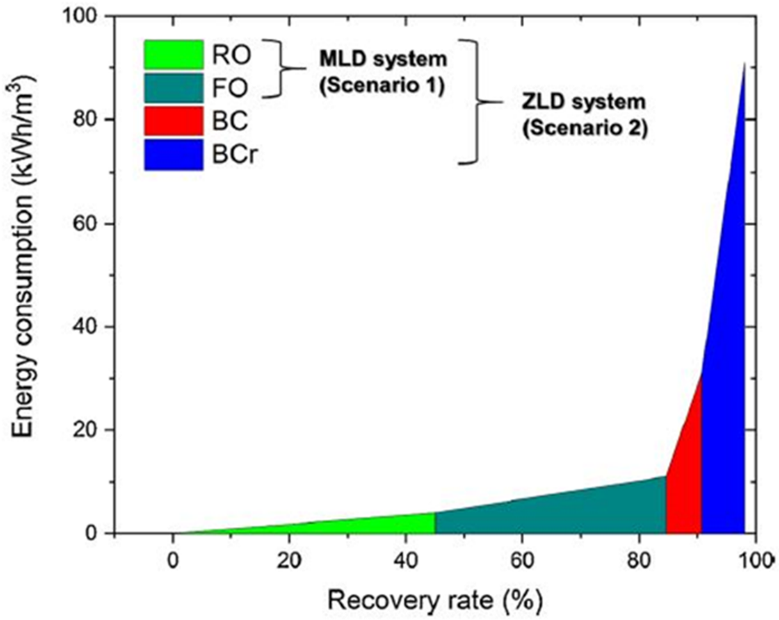


Figure 11: ZLD and MLD costs and recovery percentages (Panagopoulos, 2020)

2.3. Life Cycle Assessment

2.3.1 Overview

Water is the primary root of both human sustenance of life. It becomes even more critical when it comes to insufficient water. Water shortage issues are becoming more severe due to decreased rainfall, a greater demand for a quickly increasing population, a total exhaustion of water supplies and a lack of a regulatory system for water management. Either the freshwater source is to be recreated or the wastewater treatment methods are to be improved to ensure a sufficient supply of water. The latter choice is significant, as different treatment technologies can be established where wastewater could be handled and used for applications such as planting and swimming (Raghuvanshi, 2016)

One of several instruments that can do this evaluation is the Life Cycle Assessment (LCA), which is focused on a perfect knowledge of the device amount of practical data gathered.

Life Cycle Assessment (LCA) is characterized as the collection and analysis of the inputs and possible environmental effects of a commodity system during its life cycle. LCA studies assist in the determination of the right procedure from an environmental perspective. Four phases are required for the LCA study: target and scope description, Life Cycle Inventory Analysis (LCI), Life Cycle Impact Assessment (LCIA) and interpretation (Raghuvanshi, 2016)

The significance of LCA water treatment processes has been established in relevant research due to its holistic approach. Several investigations have been carried on drainage issues with the LCA. However, one recent research compared the various wastewater treatment methods: aerobic versus anaerobic, chemical versus combined chemical and biological. Phosphorus recycling of farmland (due to its capacity for fertilizer) has been stated to be more appropriate to reduce the effects of fossil fuel depletion and climate change relative to sludge incineration. In this report, the Life Cycle Evaluation established by the international standard organization is used to determine the environmental effects of the wastewater treatment process at the site. The effects are measured by a basic LCA, which is structured to model and evaluate the environmental effects of the wastewater treatment process (Raghuvanshi, 2016).

2.3.2 LCA applied in wastewater treatment field and industrial symbiosis

From the very first cases released, the focus of LCA studies concerning wastewater management was on the consumption of energy and capital. In recent years, and in response to the global warming potential, the use of characterization has expanded. Also the effect groups synonymous with toxicity are now more commonly used. It is increasingly used to apply LCA to measure prevented against caused impacts, and to recognize trade-offs when implementing new technologies (Larsen, 2017).

The handling of one cubic meter of wastewater, which should be well described with regard to composition, is a standard functional unit. Based on the objective and nature of the analysis, all life-cycle phases have the possibility to be relevant, while the disposal of facilities tends to be the least critical for the impact profile in many situations. No inventory data so none of the conventional categories of impact (with the exception of stratospheric ozone depletion if N2O emission is excluded) should be excluded, but eutrophication and Eco toxicity are dominant in many cases (Larsen, 2017)

The pros and cons of each process should be addressed to be analyzed in depth and among alternative methods of treatment; The most environmentally sustainable care choices, in particular the least energy-consuming methods should be chosen and applied. Development and installation of the most suitable wastewater Treatment plants would be beneficial to use the LCA method and Various environmental effects of wastewater treatment facilities should be addressed Identify using the LCA process. Further analysis should be carried out for an assessment of the effect of wastewater treatment methods on the life cycle (Larsen, 2017).

2.3.3 UMBERTO Software

A Life Cycle Assessment (LCA) is a tool for measuring the effect of a commodity on the environment (footprint) over its entire life cycle. In this sense, resources are often included in the word 'product'. Taking into account the entire product life cycle, from resource extraction to processing, usage and recycling, ensures an integrated measurement of both inputs and outputs, thereby ensuring that harmful environmental effects are not transferred to the product's other life cycle processes. In the ISO 14040/14044 DIN standard, this approach is specified. In certain cases, for example, instead of examining the full product life cycle ('cradle-to-grave'), it is sufficient to restrict the device limits to the 'grave' approach.

LCA software helps you to build a blueprint of the whole structure of your product. Umberto is a computer perfect answer for material and energy flow modeling established by IFU, Hamburg. This analysis tool facilitates the LCA research of the commodity and process with an eco-inventive dataset built by the Swiss Center for Life Cycle Inventory. The Umberto kit consists of an eco-invented database for the LCA analysis. In LCA, three fields of empirical expertise and logic are discussed in the study. "The fields are often referred to as "spheres". In the tests, the concept of such logic and empirical expertise was discussed. As follows, the three factors are:

- Techno sphere: the life cycle description, the process pollution, the transfer procedures are based on causal links.
- Ecosphere: The "environment" is influenced by modeling variations (damages).
- Sphere of value: the modeling of the presumed importance of these modifications (damages), as well as the maintenance of the Techno- and Ecosphere modeling options.

You start by creating a raw material network using Umberto LCA+. In the realization of the limitations of the method, automated databases such as Ecoinvent or GaBi are useful. A vast amount of data set is now in these libraries, allowing you to quickly imagine the history structures.

The app will complete the next two steps of LCA, the life cycle inventory review and the life cycle impact evaluation for you. You then view the observations and analyze them. The LCA platform has functions that make it easier to analyze the results in such a manner that they can potentially be used to minimize waste pollution, for example. One of the functions is to represent outcomes, which is helpful in ensuring an understandable interpretation of the outcome.

If individuals are planning to use the findings of the LCA program review in your sustainability reporting, or would like to explore it with your peers – let the audience see at a glance where the key points inside your development system are. In the end, the app facilitates a higher understanding of processes and helps establish greater clarity.

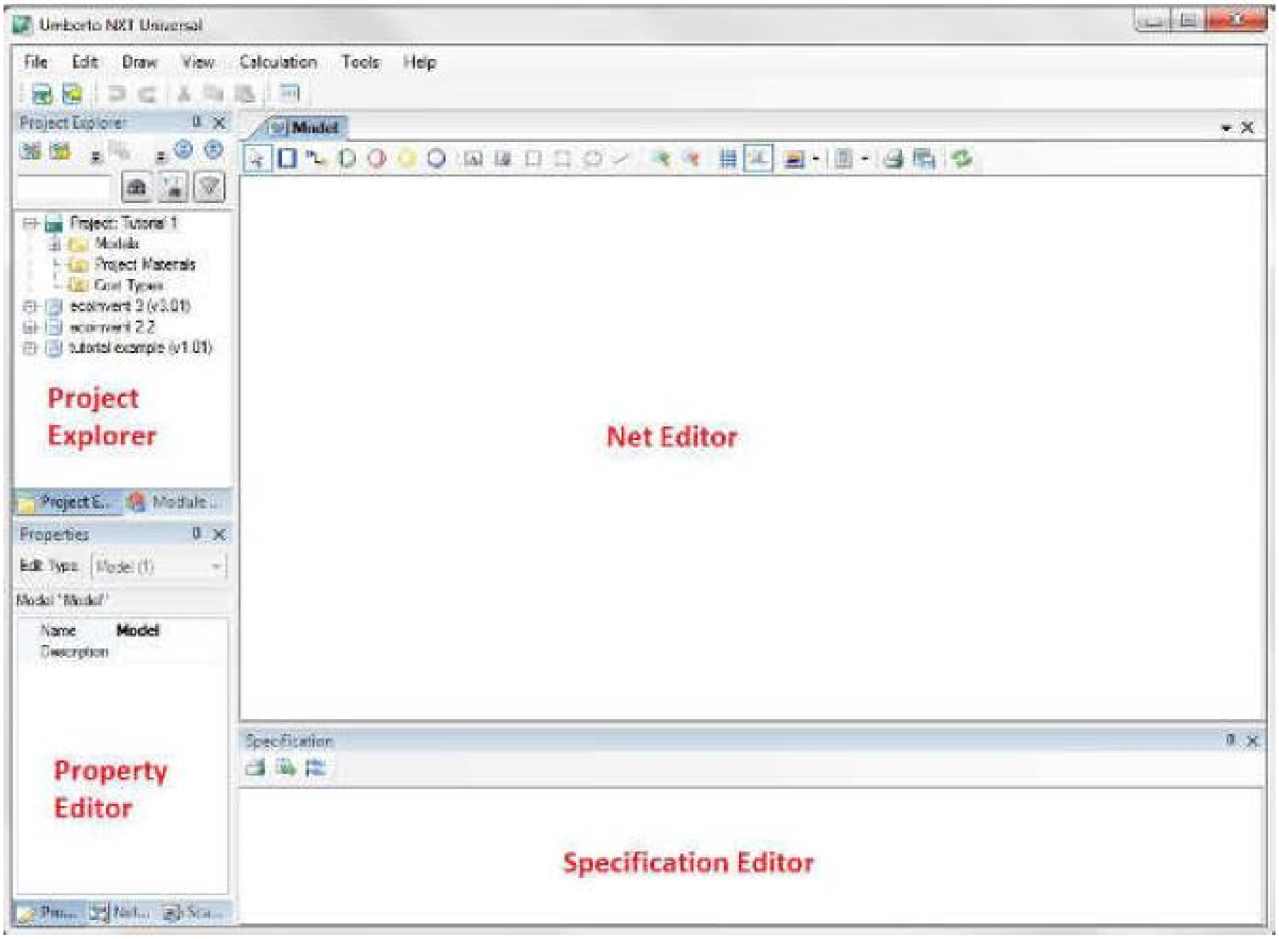


Figure 12: Graphical User Interface of Umberto NXT LCA (IT, 2020)

The largest window is called 'Net Editor'. The net editor allows for creating a graphical model. The window pane on the top left is the so called 'Project Explorer'. It shows all models and materials which are contained in the respective Umberto project file.

At the bottom left there is the 'Property Editor' window panel. The first information on the top of this window shows the type and name of the selected element. Further properties of this element are also displayed and can be edited here.

At the bottom of the net editor the 'Specification Editor' is located which allows for specifying the elements of the model. This pane is also used to show the calculation results. Since no network has been created yet, the specification editor is empty.

Here is the elemental illustration of the created segments within the software with an input and energy consumed.

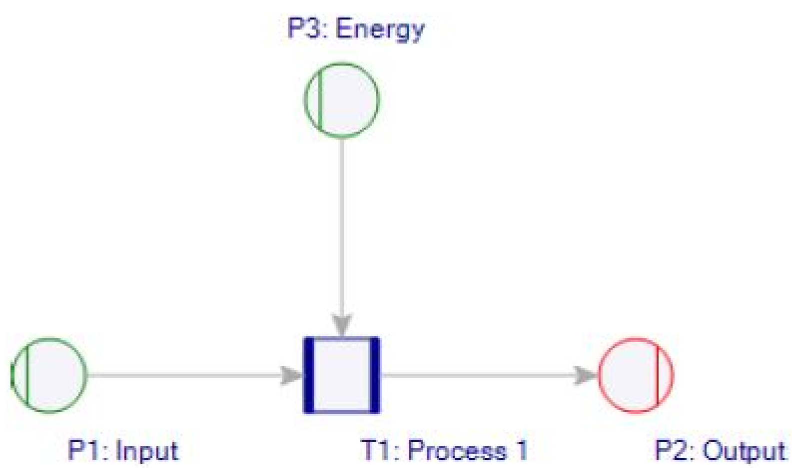


Figure 13: Expanded model (process 1) (IT, 2020)

A pre-requisite leap forward to an LCA technique is the Aim and scope which in turn includes the Data Collection in order to form the frame work to start from. As with the current study, the below mentioned four-step classification was followed.

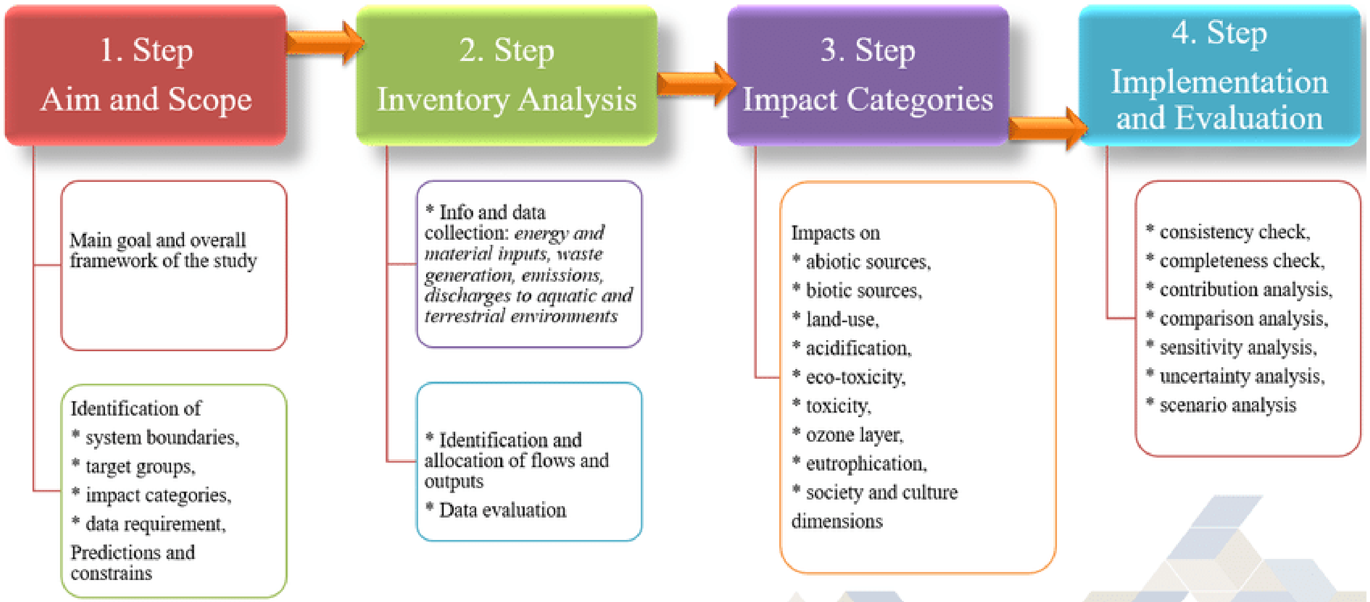


Figure 14: LCA sequential procedure (IT, 2020)

From the initial steps and on, the first and foremost goal was the scope and classifications of the targets of the analysis. A significant outcome was LCI which is simply the Inventory. The data consists of all the chemicals, electricity and fuels consumed be it on-site or as of transportation purposes to the site itself.

The data was collection was firstly attempted via direct and on-site sheets as the analysis feed while, as one obstruction on the way some literary estimations had to be applied for the convenience of the study necessities.

However, the following highlights were provided following the analysis itself; Life Cycle Impact Analysis which is addressed by the figures presented by Umberto software and Life cycle cost which was not included in this study.

3. MATERIALS AND METHODS

In this study a literature review was performed primarily to support and corroborate the requirements of the plant to the edge of the up to minute technologies in the realm of scientific researches as far as the publications availability goes.

The literature review sections have focused more on the Zero Liquid Discharge plants, Industrial symbiosis, technologies and configurations in addition to economic-environmental considerations.

In the second approach of this study, the plant scheme has been spotted as the scope of mass balance which necessitated data collection from wastewater characteristics by both Rosignano and Cecina plants measured values. A supportive ligature review has been paid to theoretically safeguard the plant stages' efficiencies as far as the validated resources were available.

A full mass balance chart from Jan 2016 to the Dec 2019 has been set associated with all the daily and overall average load values to have a clear understanding of the current situation.

Thirdly, to serve as a net Life Cycle Analysis including the Carbon Footprint and Global Warming parameters; all the chemicals and electricity consumed by each stage of the plant has been acquired and applied to the software Umberto.

3.1. CASE STUDY: Aretusa Recovery Plant

As already explained, the wastewater reuse plant of Aretusa receive the effluent coming from the two WWTPs of Rosignano and Cecina.

Aretusa plant serves as the role of the circle-closure and supports the circularity through the water nexus which herein consists of the triangle of Cecina, Rosignano and Aretusa itself. As far as the symbiosis concept goes, the tri-angle materializes the guides and lines to follow in practice by the utilization of the outflows from other plants and minimization of the pollutants discharge.

As for the influent waste characteristics, data has been collected to develop and establish a mass flow analysis and the steps has been thoroughly followed to secure the validity of missing data due to lack of measurements at times and literary reviews were performed as to the scope of each and every treatment stage.

3.1.1 Description

The main objective of the Aretusa plant is to make the wastewater usable by the industrial partner Solvay. In order to do this the following processes are applied:

1. Equalization;
2. Coagulation and flocculation;
3. Sedimentation;
4. Sand filtration;
5. Biological active carbon filter;
6. Granular active carbon filter;
7. UV sterilization.

In particular, the first equalization phase is necessary in order to mix the two flows coming from Cecina and Rosignano. After this the coagulation and flocculation step is made of two parallel lines, each one composed of three different tanks. In the first tank a fast mixing takes place in order to properly mix the coagulating agent. After this a medium and then a slow mixing is applied to allow the flocculation process. Finally, for the removal of the flocculated sludge a sedimentation step is included. The clarified water with low solids content leaving the settler is fed to the sand filtration unit. This phase leads to the elimination of suspended solids with the achievement of a turbidity-free flow. The activated carbon bio-filtration unit is currently bypassed and the outgoing flow from the sand filtration is fed directly to the granular activated carbon filters. Finally, as last stage of treatment, disinfection by UV rays is provided.

The flow scheme of the plant is shown for a better understanding of the configuration of the plant.

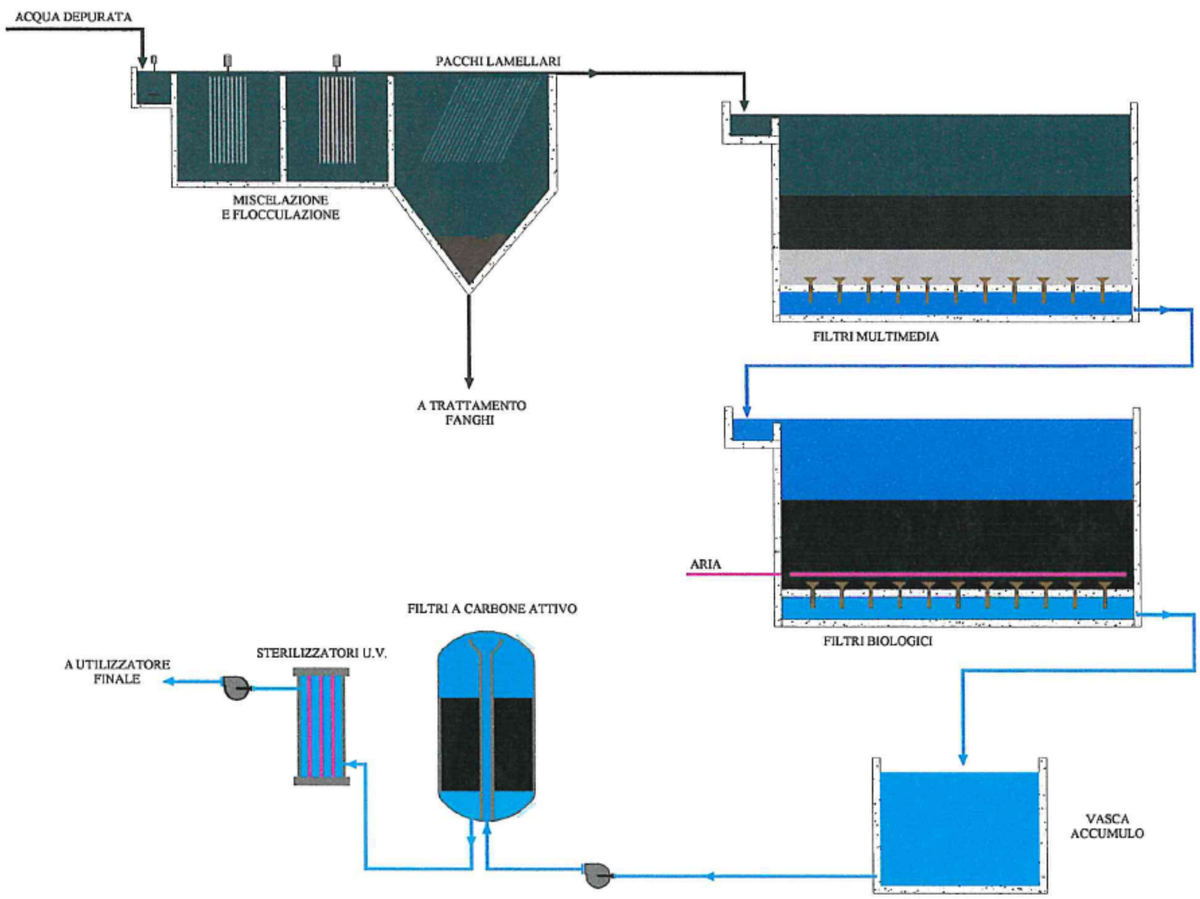


Figure 15: Flow scheme of Aretusa plant

3.1.2 Collection and organization of real data

The time scope in this study has been set on a two-year period starting from Jan, 1st, 2018 and extending to the Dec, 29th ,2019.

The data was collected through the directly measured values derived from on-site measurements presented and validated by the in-charge authorities for a safe and secure estimation albeit with few gaps which have thoroughly been plugged by theoretical and literary estimations performed thus far.

The data was sorted and analyzed to produce every detail needed as for the characteristics of the effluent flows of Cecina and Rosignano and the influent and effluent flows of Aretusa.

3.2. Life Cycle Assessment

As introduced before in order to perform a LCA of Aretusa WWRP a specific methodology was followed. In the following paragraphs indications for each step are given.

3.2.1 Target and scope description

The main target of the performed LCA was to assess Aretusa impacts and, in particular, how the impact is reduced when wastewater is reused by Solvay, instead of being discharged in surface water. For this reason, a functional unit is chosen. The functional unit is a measure of the function of the studied system and it provides a reference to which the inputs and outputs can be related (ec.europa.eu, 2020). Within the present study is the quantity of wastewater inflow and treated by the sewage treatment plant per day.

3.2.2 Life cycle inventory

This section includes the impacts applied throughout the whole stages from cradle to grave, specifically on global warming and carbon footprint which are seen underneath the following relevant subsections.

The process starts from plant scheme and subsequent flows from the influent of each stage to the final effluent. The data has been collected both empirically and theoretically.

The plant scheme shows a merged inflow from two different outflows, namely Rosignano and Cecina plants. However, the statistical data had come short at points, this void has been compensated through literature values for convenience of the study. In particular data related with energy consumption of each stage were found in the (D3.4: ENERWATER methodology). In the table below the data applied for the LCA are summarized:

	Value	Dimension	Value	Dimension
Coagulation	1,971	KWh/Yr	0.002	KWh/m3
Flocculation	27,885	KWh/Yr	0.02	KWh/m3
Mixing	35,452	KWh/Yr	0.028	KWh/m3
UV-Disinfection	203,200	KWh/Yr	0.16	KWh/m3
Total energy (Ave.)	557,707	KWh/Yr	0.44	KWh/m3

Table 2 The energy consumed by each stage of the plant values

3.2.3 Life cycle impact assessment

Finally, the Umberto software was applied in order to assess the impact of two different scenarios. In the first one the wastewater effluent from Aretusa is discharged on the environment, while in the second one is reused by Solvay.

In both the scenario the impact of Aretusa WWRP in terms of energy consumption and sludge treatment was assessed together with the impact of the final discharge.

The two scenarios were chosen in order to quantify the impact reduction that the symbiosis between the water utility and the industrial partner allow. In the second scenario, indeed, water reuse is the core approach which in turn reduces the freshwater utilization and hence freshwater depletion. As mentioned above, the main role of Aretusa is to embody such industrial symbiosis and induce symbiotic water re-use instead. Particularly, the analysis performed in the present work consider only the Aretusa impact reduction connected with the absence of a direct discharge in water bodies.

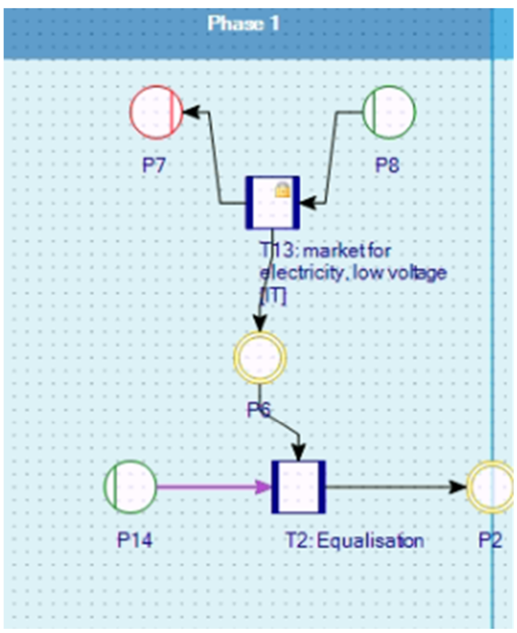
Scenario 1: Discharge on the environment

In the first scenario analyzed it was assumed that the effluent flow of Aretusa was discharged into a surface body. In order to create this scenario, each phase of the Aretusa WWRP has been implemented in Umberto software.

The first phase is the equalization phase (Figure 16), in this case as input both wastewater and electricity were added. Particularly, a specific electricity production process was identified from the Eco-invent database and imported in the model.

The same input where identified for the second phase; flocculation and coagulation (Figure 17). For the sedimentation step (Phase 3, Figure 18) together with the effluent wastewater also the sludge production and treatment were considered. Since the sludge produced by Aretusa is treated at the Rosignano treatment plant a specific process of anaerobic digestion was identified in Eco invent and imported in the model. In this way, also the impact produced by the sludge treatment is considered in the Umberto simulation.

Concerning phase 6 (Disinfection), also in this case the electricity consumption was inserted as the input (Figure 19). Finally, a specific phase 7 was introduced only for the final discharge of the system. In this case specific impact of nutrients was assessed inserting the data coming from the previous elaboration (Figure 20).



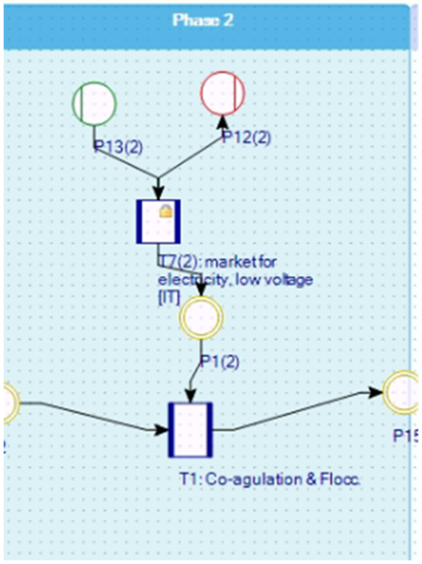
INPUT

Material	Place	Material Type	Coefficient	Unit	Price	Value	Fu
wastewater	P14	Good	3,682,850.0	m3	0.00 EUR/m3	0.00 EUR	
electricity, low voltage	P6	Good	103,676.02	kWh	0.00 EUR/kWh		

OUTPUT

Material	Place	Material Type	Coefficient	Unit	Price
wastewater	P2	Good	3,682,850.0	m3	0.00 EUR/m3

Figure 16: Umberto software – Phase-1 modeling



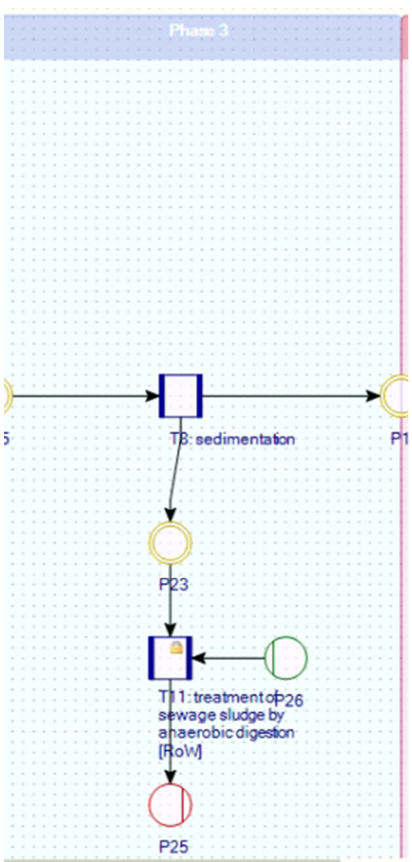
INPUT

Material	Place	Material Type	Coefficient	Unit	Price	Value
wastewater	P2	Good	3,682,850.0	m3	0.00 EUR/m3	0.00 EUR
electricity, low voltage	P1(2)	Good	5,764.00	kWh	0.00 EUR/kWh	

OUTPUT

Material	Place	Material Type	Coefficient	Unit	Price
wastewater	P15	Good	3,682,850.0	m3	0.00 EUR/m3

Figure 17: Umberto software – Phase-2 modeling



INPUT

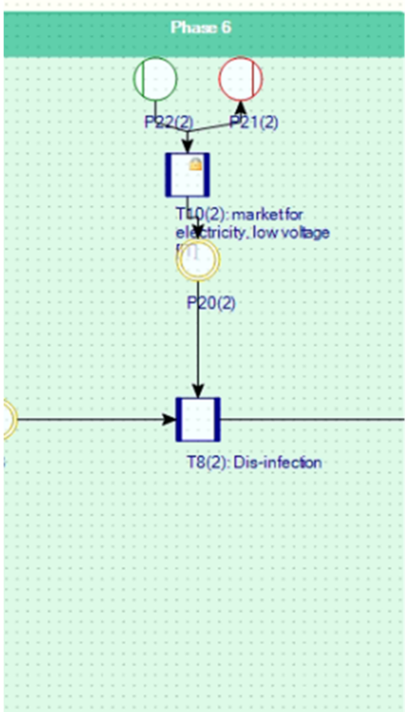
Input / Output | Generic Materials | Parameters

Material	Place	Material Type	Coefficient	Unit	Price	Value
wastewater	P15	Good	3,682,850.0	m3	0.00 EUR/m3	0.00 EUR

OUTPUT

Material	Place	Material Type	Coefficient	Unit	Price
sewage sludge	P23	Bad	580.00	m3	0.00 EUR/m3
wastewater	P15(3)	Good	3,682,850.0	m3	0.00 EUR/m3

Figure 18: Umberto software – Phase-3 modeling



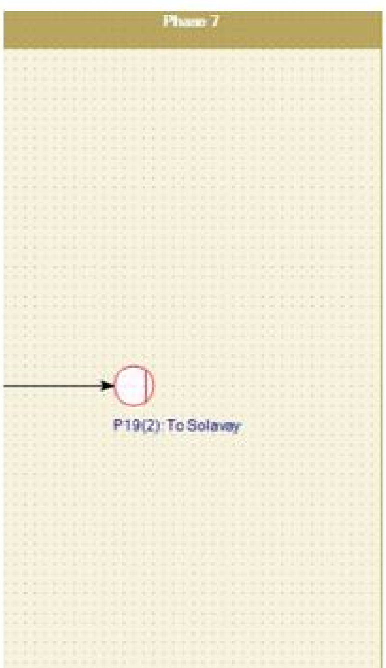
INPUT

Material	Place	Material Type	Coefficient	Unit	Price	Value
wastewater	P3	Good	3,682,850.0	m3	0.00 EUR/m3	0.00 EUR
electricity, low voltage	P20(2)	Good	594,239.18	kWh	0.00 EUR/kWh	

OUTPUT

Material	Place	Material Type	Coefficient	Unit	Price
Nitrogen [water/surface water]	P19(2): To Solav	Bad	-69,020.00	kg	0.00 EUR/kg
Phosphorus [water/surface water]	P19(2): To Solav	Bad	-20,876.00	kg	0.00 EUR/kg
wastewater	**P19(2): To Sola**	**Reference Flow (Go**	**3,682,850.0**	**m3**	**0.00 EUR/m3**

Figure 19: Umberto software - Phase-6 modeling



OFINAL UTPUT

Material Type	Material	Stock Type	Begin Quantity	End Quantit	
Bad	Nitrogen [water/surface water]	Calculated	0.00	-1.87	kg
Bad	Phosphorus [water/surface water]	Calculated	0.00	-0.57	kg
Good	wastewater	Calculated	0.00	100.00	m3

Figure 20: Umberto software - Phase-7 modeling

In the following figure the representation of the complete model is reported.

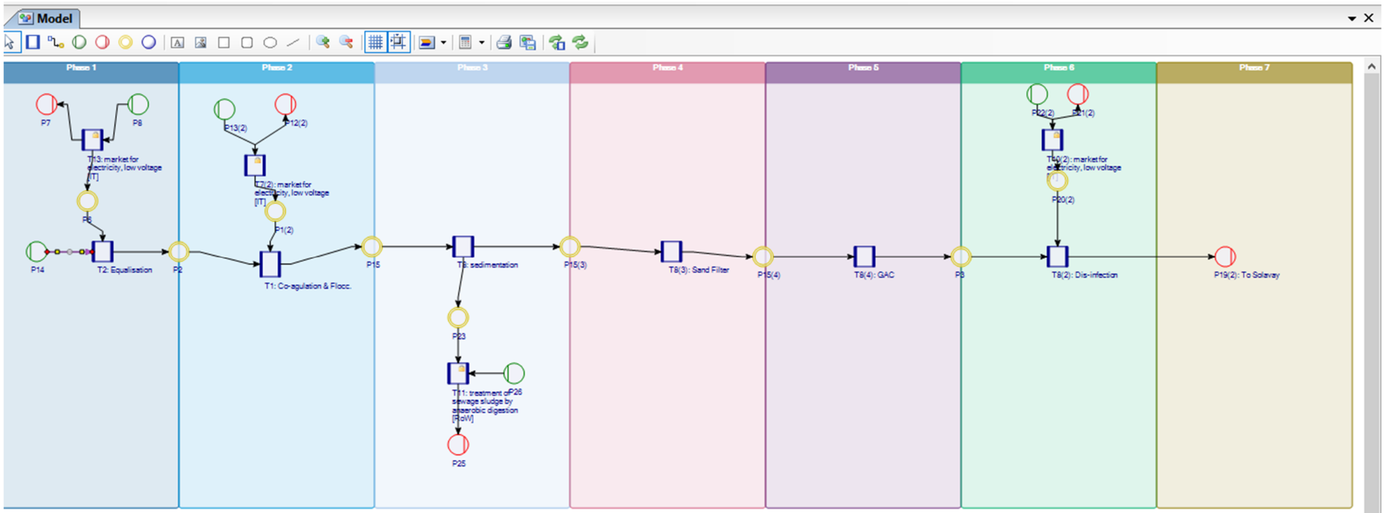


Figure 21 The plant scheme in the Umberto model

Scenario 2: Discharge on SOLVAY chemical industry

In the second scenario in order to highlight the importance of the symbiosis with the industrial partner, a different discharge was implemented in the model. In this case the general scheme was maintained as in the previous scenario, but the discharge was not released in the environment, but was delivered to Solvay for its industrial processes.

4. RESULTS AND DISCUSSION

In this chapter the specific analysis performed and already explained in the Material and methods section are going to be showed and commented.

4.1. Elaboration results for Aretusa Recovery Plant

The analysis for Cecina and Rosignano WWTPs and for Aretusa WWRP are carried out from 2018 to 2020.

The historical data were analyzed in order to obtain information about the effluent of Cecina and Rosignano and the influent of Aretusa. In particular, the flows are investigated to understand which one of the two WWTPs effluents influence the most in terms of quantity. Then the qualitative analysis for all the three plants are reported and analyzed. The focus is on the principal macro pollutants of COD, TSS, N, P and Chlorides. Finally, the effluent of Aretusa WWRP is showed. All those elaborations will be used in the LCA elaboration in order to insert data in the Umberto Software.

4.1.1. Rosignano and Cecina effluent analysis

The two plants of Cecina and Rosignano are characterized by a double effluent: part of the flow is discharged directly in water surface bodies (discharged effluent) and part is sent to Aretusa plant for further treatment before being reused by Solvay (reused effluent). In the following Figure 23 a comparison between the reused effluents of Cecina and Rosignano and the influent of Aretusa are shown.

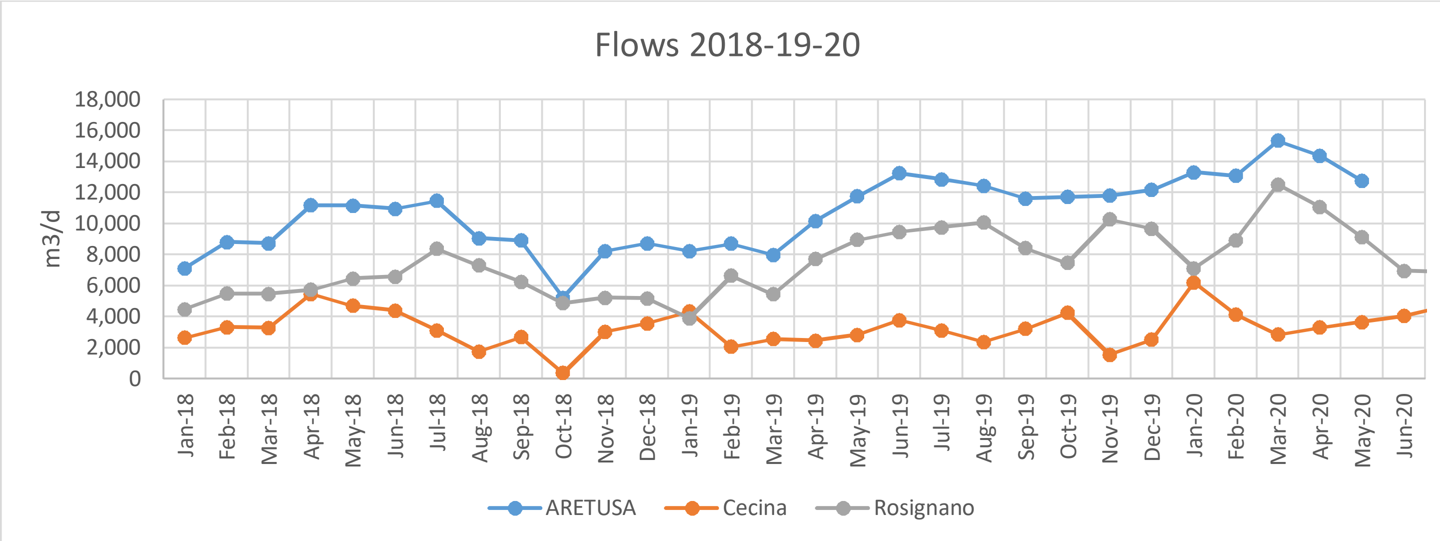


Figure 22 Cecina, Rosignano and Aretusa Flows

A merged flow containing Rosignano represents the main contribution in terms of quantity. In the following paragraphs the historical quality data of the flows are reported.

4.1.1.1. Quality of Cecina plant's Flow

Here below, the Cecina effluent main characteristics along with time, ranging from Nov, 2018 to Dec, 2019, is visualized.

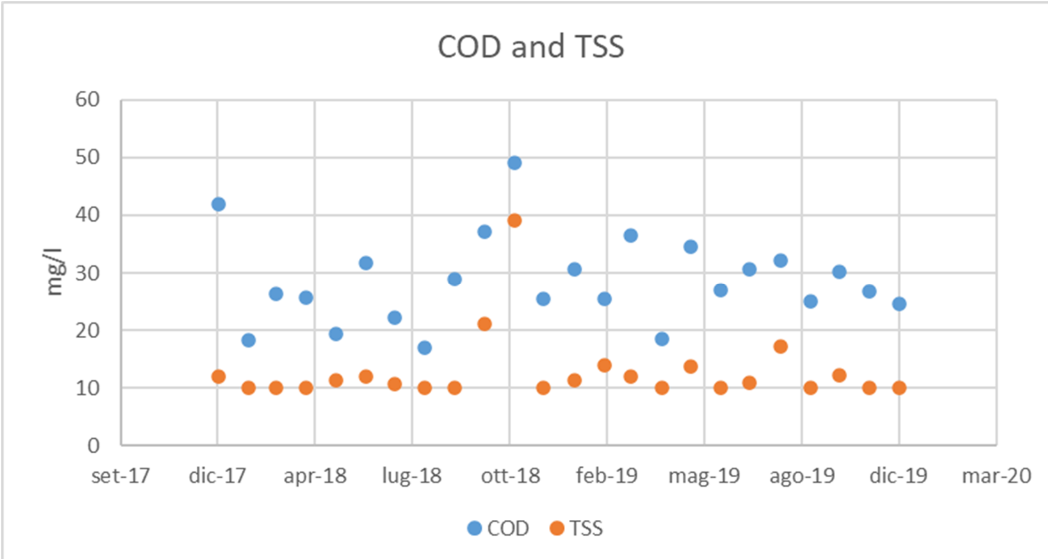


Figure 23 Cecina Effluent COD & TSS

Concerning the TSS the values are almost always around 10 mg/l, this is probably due to the limits of the instrumentation. So, it can be supposed that in general the effluent has TSS lower than 10 mg/l with some isolated peaks. A wider variability can be observed for the COD which have effluent values ranging from 20 mg/l to 50 mg/l.

Concerning the nutrient discharged, concentrations of Ammonia and Phosphorus are shown in Figure 24. The Ammonia is always very low, with concentrations below 3 mg/l and only some isolated exceptions where concentrations of 9 mg/l are reached. Phosphorus values are pretty high, with values often higher than 2 mg/l.

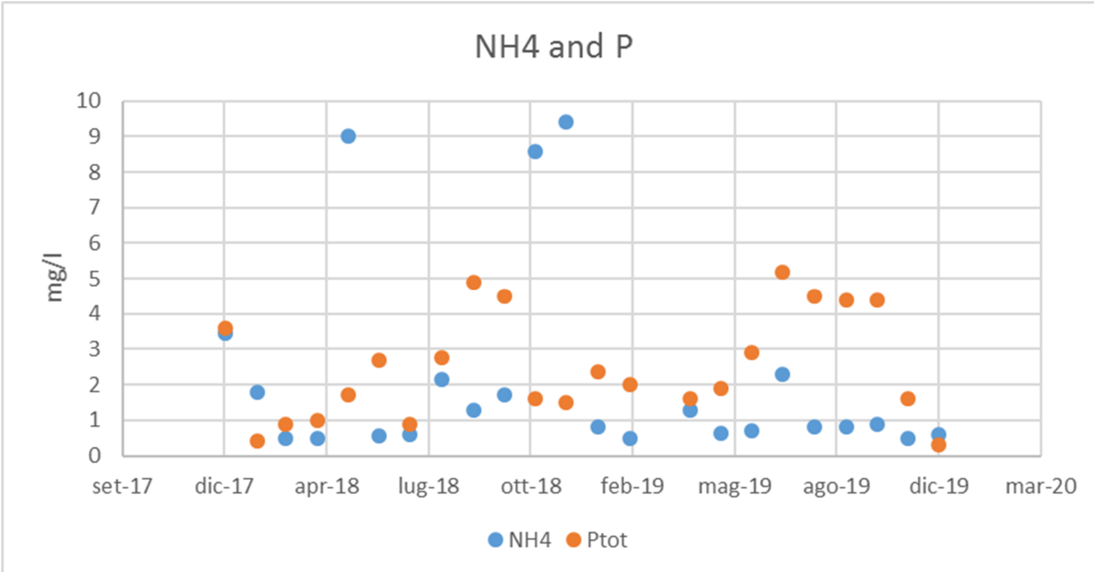


Figure 24: Cecina Effluent NH4 & P

Finally, chlorides concentrations are shown (Figure 25) and the trend implies a big variability with maximum values of 650 mg/l and minimum of 100 mg/l.

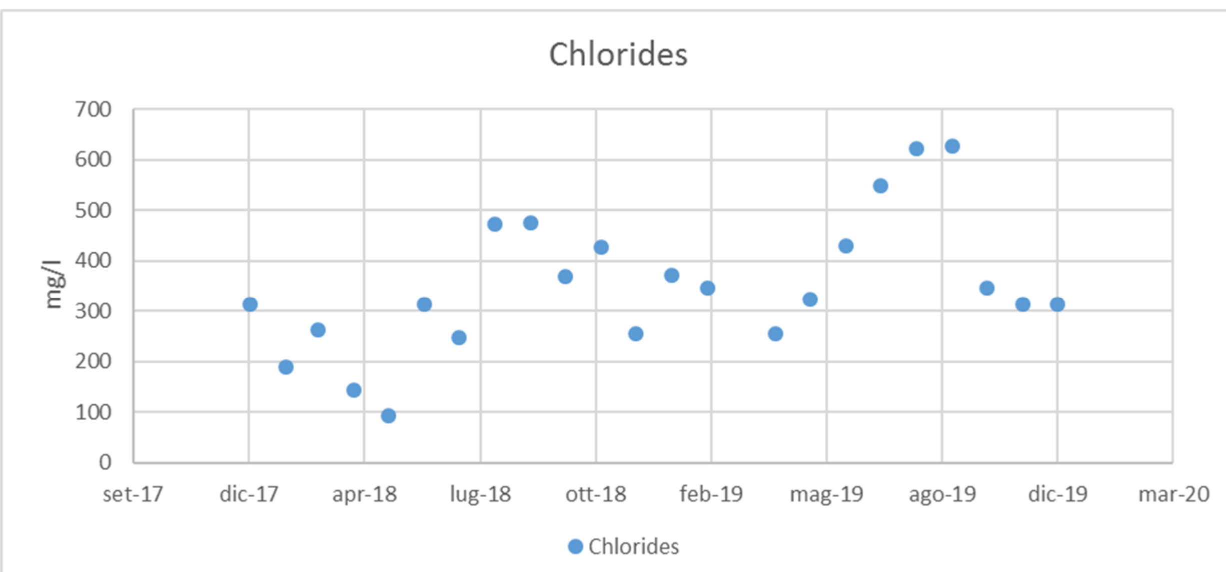


Figure 25 Cecina Effluent Chlorides & TSS

In the following table the loads outing Cecina plant are showed.

Table 3: Cecina effluent Loads over the time scope (part 1)

MONTHS	Effluent loads				
	Chlorides	COD	TSS	NH4	Ptot
	kg/d	kg/d	kg/d	kg/d	kg/d
gen-18	1692	227	65	19	19
feb-18	1246	121	66	12	3
mar-18	1739	175	66	3	6
apr-18	1536	275	107	5	11
mag-18	873	182	106	85	16
giu-18	2808	284	107	5	24
lug-18	1495	134	65	4	5
ago-18	1652	60	35	8	10
set-18	2588	158	55	7	27
ott-18	1415	143	81	7	17
nov-18	2573	295	234	52	10
dic-18	1747	173	68	64	10
gen-19	2041	168	61	4.	12
feb-19	1757	129	71	2	10
mar-19	0	160	52	0	0
apr-19	1363	98	53	7	8
mag-19	2039	218	86	4	12
giu-19	2883	180	67	4	19
lug-19	3975	221	79	16	37
ago-19	4582	237	127	5	33
set-19	3829	153	61	4	26
ott-19	2110	183	74	5	26
nov-19	2615	224	83	4	13
dic-19	2232	176	71	4	2
Ave.	**2116**	**182**	**81**	**13**	**15**
Std. Dev.	**1013**	**57**	**38**	**21**	**9**

4.1.1.2 Quality of Rosignano plant's Flow

The same elaboration analyzed for Cecina plant are now shown for the Rosignano plant.

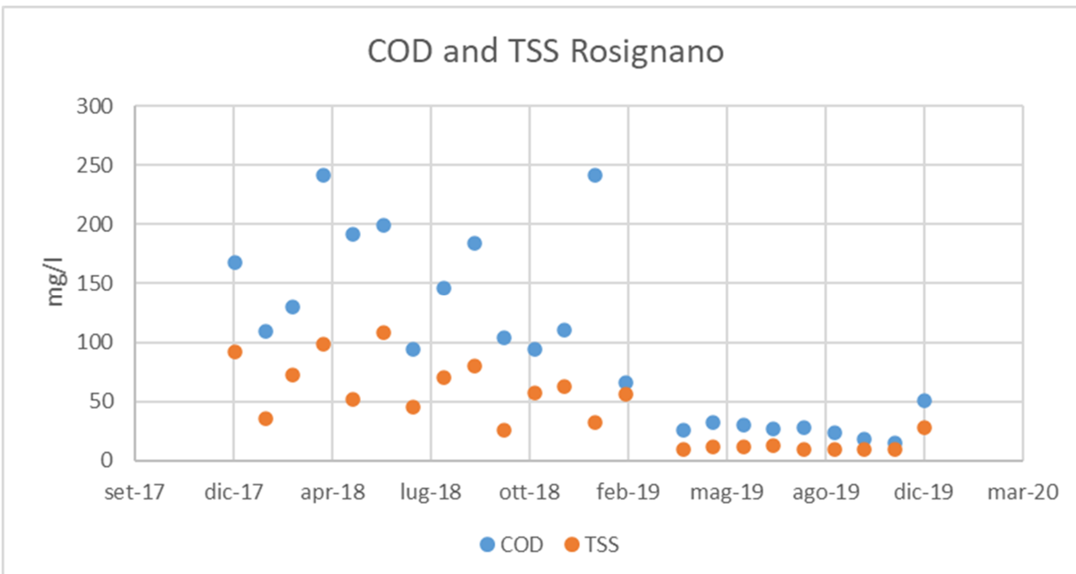


Figure 26: Rosignano Effluent TSS & COD

In this case, it is noticed that both COD and TSS concentrations were very high in 2018 where values of 250 mg/l for COD and 100 mg/l for TSS were registered. In 2019 the concentrations return to values lower than 50 mg/l for both the pollutants.

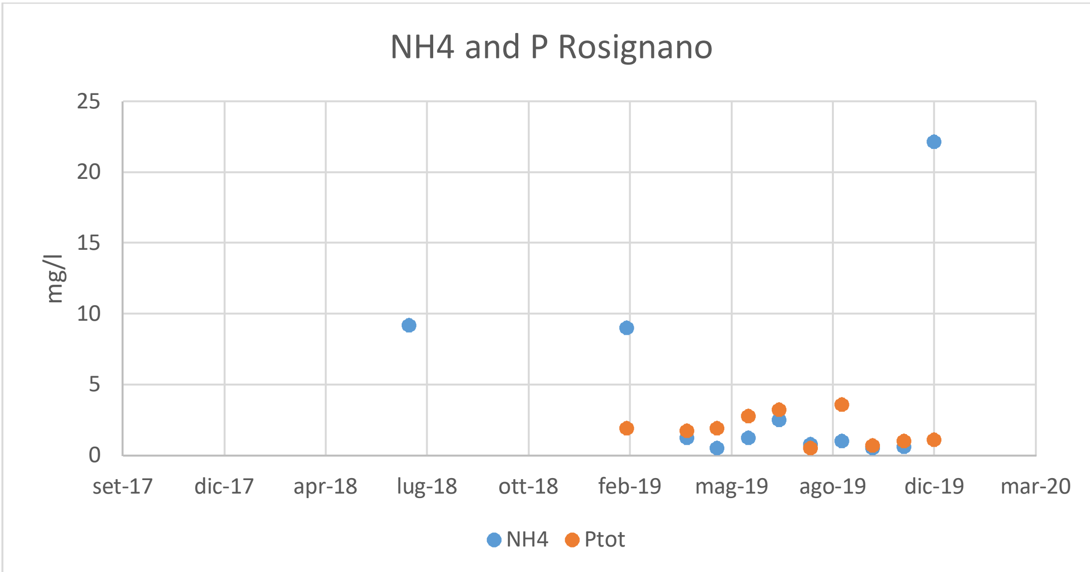


Figure 27: Rosignano Effluent (NH4 & P)

Figure 27 illustrates the effluent concentrations as of Ammonia and Phosphorus. The concentrations are always lower than 5 mg/l except from some isolated points for Ammonia where concentrations up to 22 mg/l were reached.

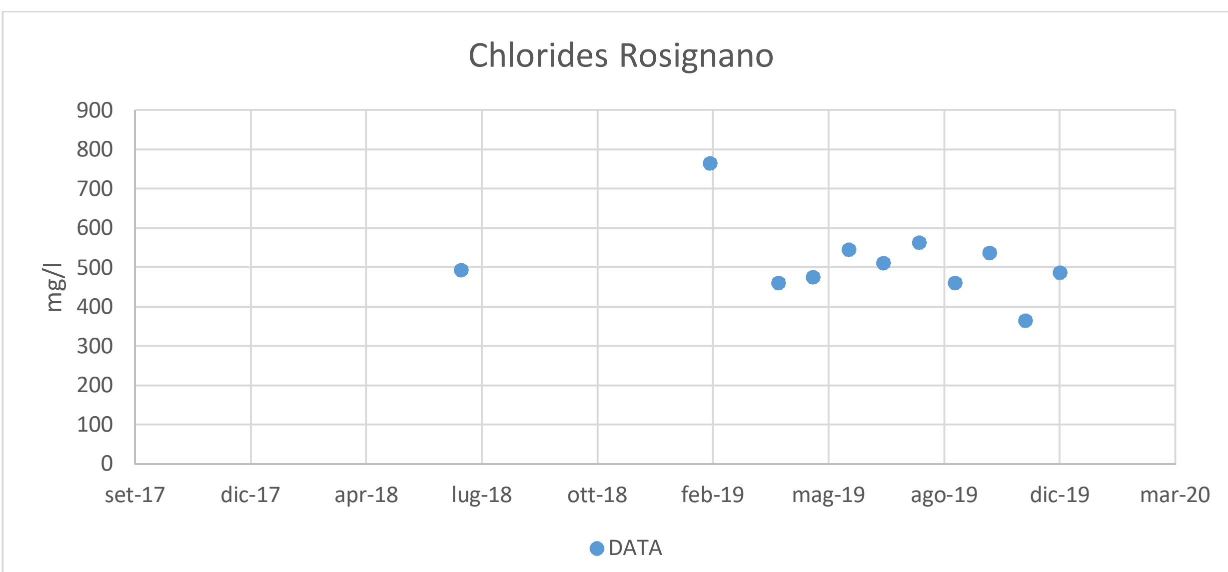


Figure 28: Rosignano Effluent (Chlorides)

Finally, Figure 28 shows the Chlorides concentration which appear to be usually comprised between 400 mg/l and 600 mg/l.

The table below presents the detailed effluent loads of Rosignano plant over the scope of time by pollutants of concern.

Table 4: Rosignano Effluent Loads over the time scope

MONTHS	Effluent loads				
	Chlorides	COD	NH4	Ptot	TSS
	kg/d	kg/d	kg/d	kg/d	kg/d
gen-18		1514			830
feb-18		1147			369
mar-18		1691			936
apr-18		3227			1307
mag-18		2507			681
giu-18		1913			1038
lug-18	4455	891	87		425
ago-18		1650			791
set-18		1479			643
ott-18		1069			267
nov-18		972			589
dic-18		877			498
gen-19		1732			230
feb-19	7375	637	86	18.29	539
mar-19					
apr-19	4321	239	11	16	93
mag-19	4710	323	4	18	113
giu-19	5275	288	12	27	108
lug-19	5814	300	28	36	144
ago-19	6688	337	9	5.	118
set-19	4160	216	9.	32	90
ott-19	4280	144	3	5	79
nov-19	5337	217	8	14	146
dic-19	5353	551	243	12	305
Ave.	**5252**	**1040**	**46**	**19**	**450**
std.	**1041**	**820**	**72**	**11**	**352**

4.1.2. Aretusa influent and effluent analysis

The Aretusa plant as a recovery plant receives its influent from the two plants re-use proportions in which Rosignano overweighs in terms of flow and hence the pollutants in the Aretusa influent characteristics. The influent and effluent measurements and recordings are analyzed in detail for a clear understanding of the process. The following figures are shown to fulfill such goal of this section of the present study.

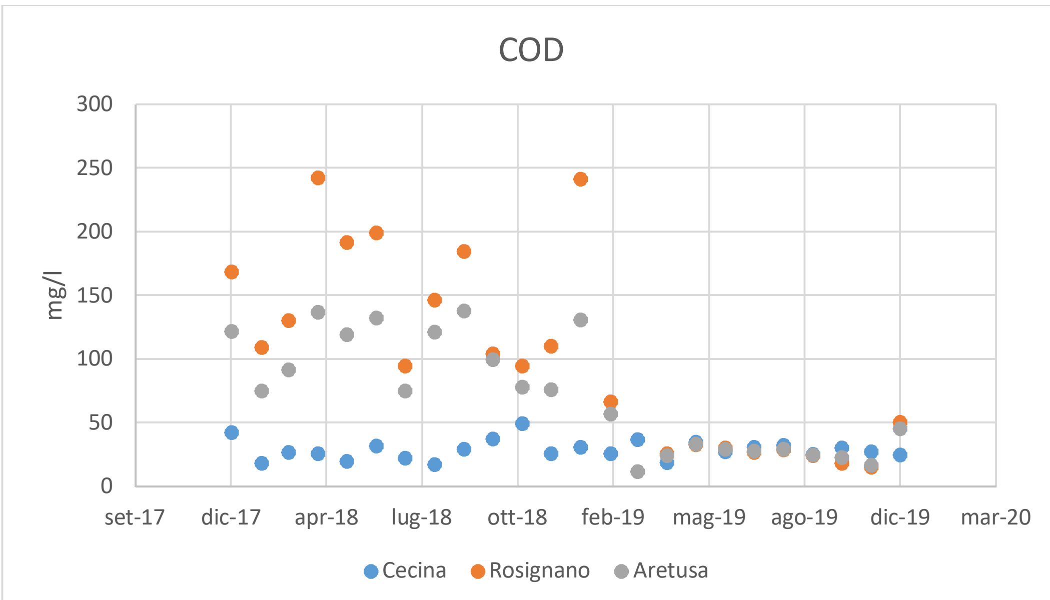


Figure 29 COD Eff. from Cecina and Rosignano and Inf. to Aretusa plant

Analyzing the COD concentrations of the three plants it can be noticed that for the year 2018 the higher COD values observed for Rosignano significantly increase the concentrations entering Aretusa. The lower concentrations coming from Cecina are unable to dilute the influential COD due to the lower quantitative contribution of this flow. In 2019 the COD concentration are always below 50 mg/l. The same observations can be done for the TSS entering Aretusa plant (Figure 30).

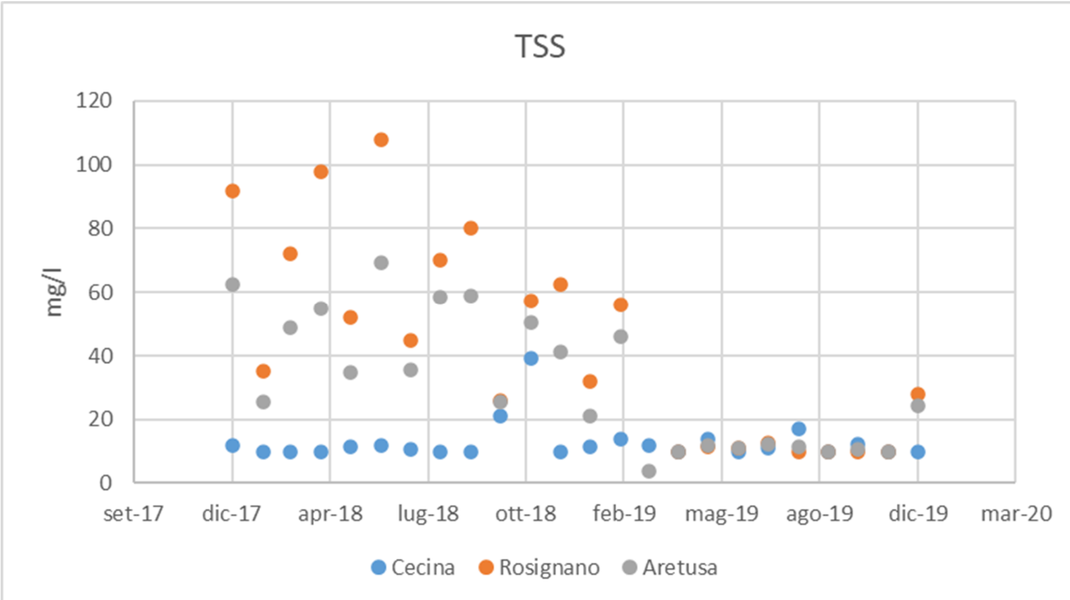


Figure 30: TSS Eff. from Cecina and Rosignano and Inf. to Aretusa plant

As to nutrients concentrations, the trends are shown in Figure 31 and Figure 32. In this case, especially for Phosphorus, the influence of Cecina's flow is more evident and produce an increase in the concentrations of Aretusa. Noteworthy to mention that as of the year 2018 the data for Rosignano are not available, so the lower concentrations of Phosphorus observed for Aretusa do not represent the real values.

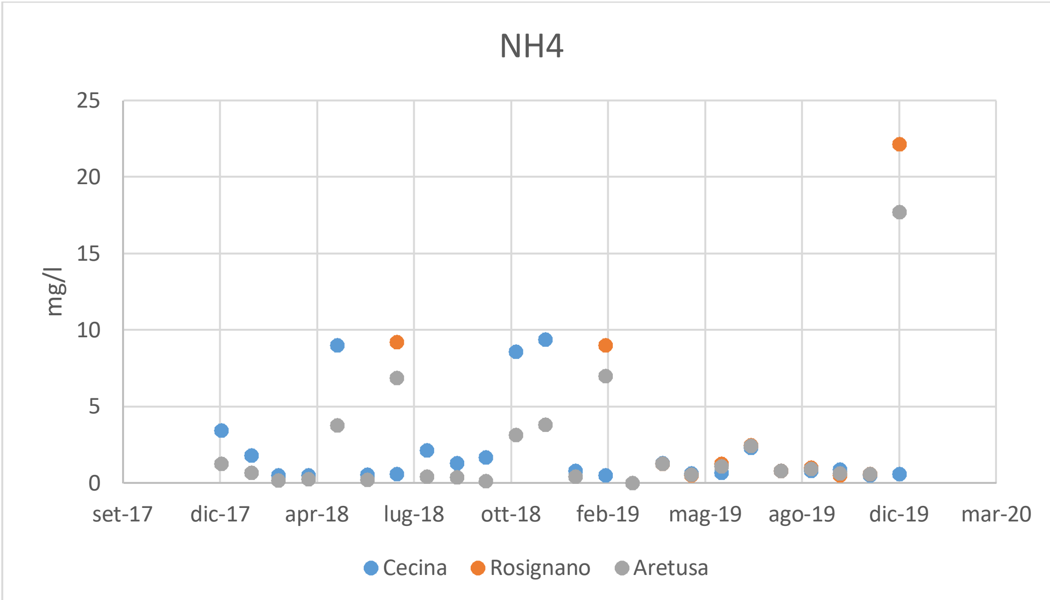


Figure 31 NH4 Eff. from Cecina and Rosignano and Inf. to Aretusa plant

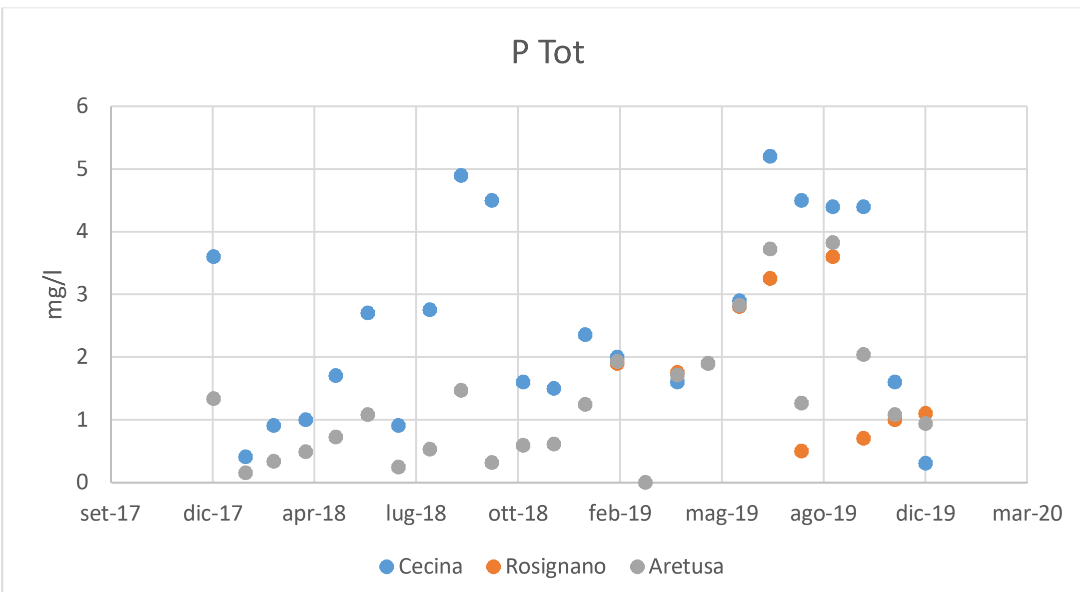


Figure 32 P Tot Eff. from Cecina and Rosignano and Inf. to Aretusa plant

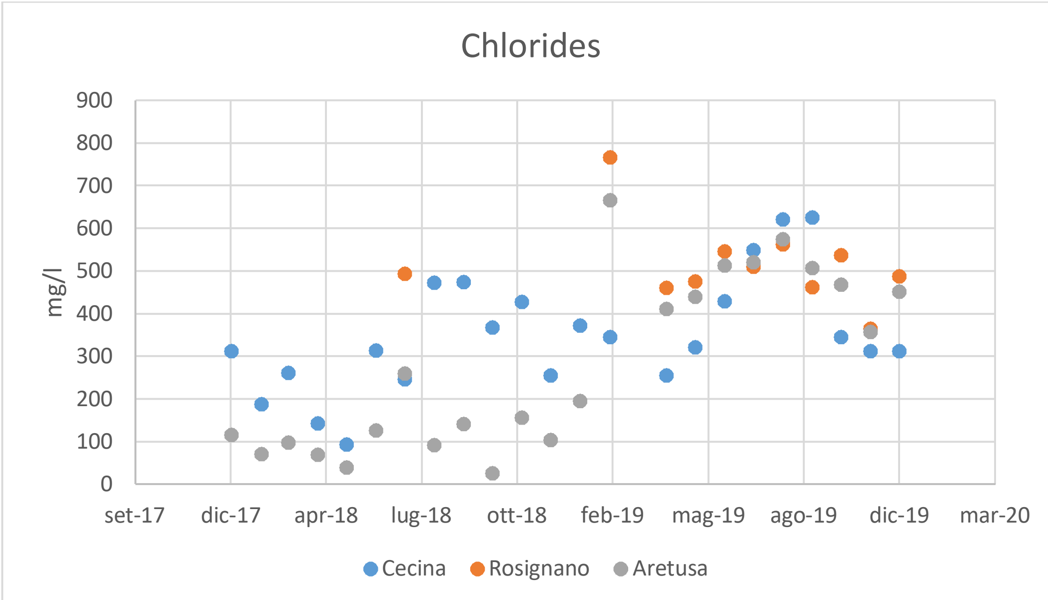


Figure 33 Chlorides Eff. from Cecina and Rosignano and Inf. to Aretusa plant

Finally, for the Chloride's concentration, considering the year 2019 the three flows have similar trend with higher concentrations in the months from July to September.

Here below Table 4**Error! Reference source not found.**the detailed values of Aretusa influent loads are reported.

Table 5: Influent loads at Arethusa

DATA	Influent loads				
	Chlorides	COD	NH4	Ptot	TSS
	kg/d	kg/d	kg/d	kg/d	kg/d
gen-18	822	861	9	9	443
feb-18	623	658	6	1	225
mar-18	858	795	2	3	426
apr-18	781	1525	3	5	616
mag-18	437	1327	42	8	389
giu-18	1380	1446	2	12	762
lug-18	2974	856	79	3	410
ago-18	826	1096	4	5	529
set-18	1265	1226	3	13	526
ott-18	134	518	1	2	134
nov-18	1291	640	26	5	416

dic-18	910	658	33	5	358
gen-19	1609	1071	3	10	173
feb-19	5800	492	60	16	400
mar-19	0	92	0	0	30
apr-19	4178	242	12	17	101
mag-19	5166	389	6	22	141
giu-19	6788	383	14	37	143
lug-19	6684	351	31	47	157
ago-19	7138	362	9	15	141
set-19	5892	282	10	44	116
ott-19	5485	262	7	23	126
nov-19	4228	194	6	12	118
dic-19	5497	546	215	11	294
Average value	**2'949**	**684**	**16**	**14**	**299**
Deviation	**2502**	**425**	**21**	**13**	**197**

At conclusion of this paragraph the effluent concentrations and loads of Aretusa are presented. In particular the graphs of the concentration of COD and Chlorides outing the plant is represented.

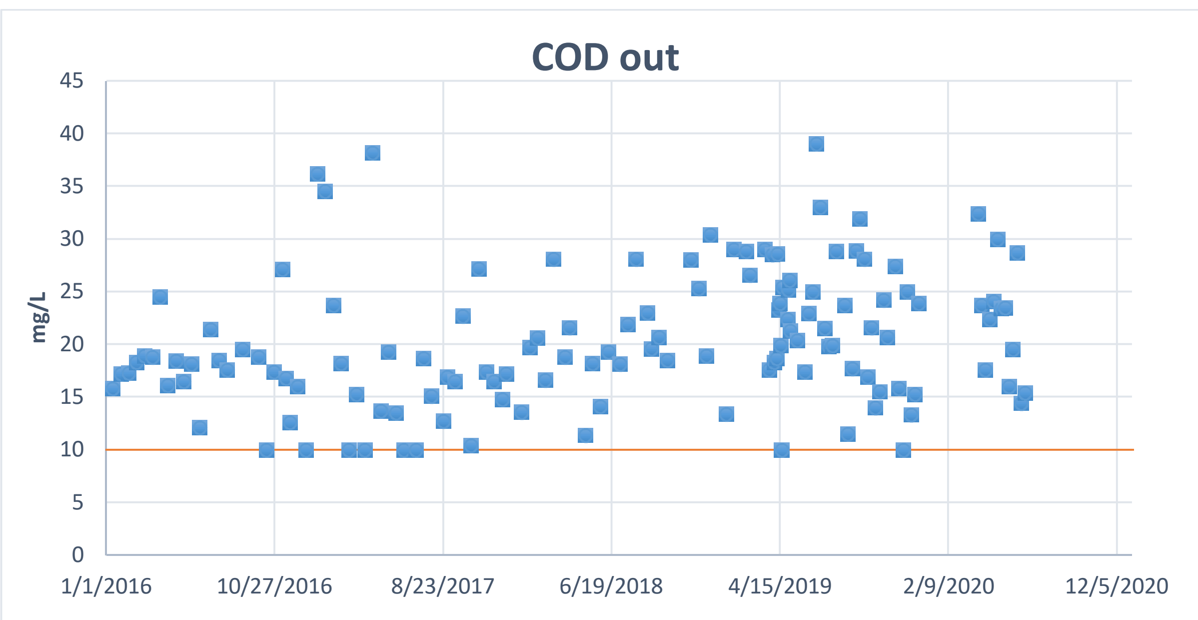


Figure 34. Effluent concentration of COD compared with the reuse limit

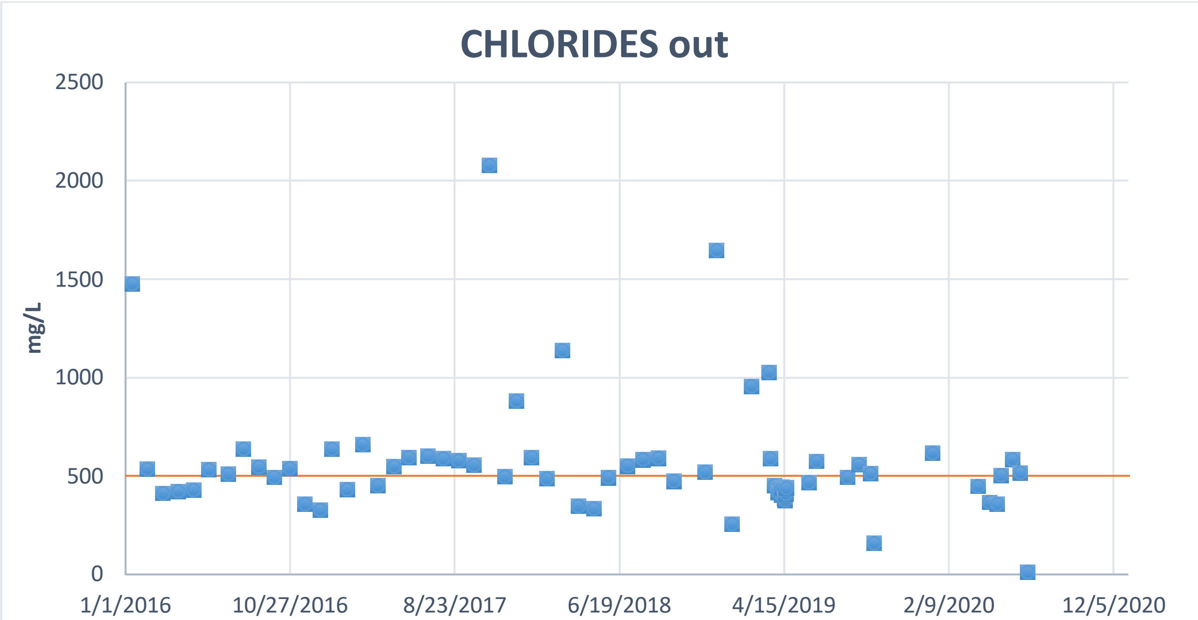


Figure 35: Effluent concentration of Chlorides compared with the reuse limit

The red line in both the graphs represent the limit for the acceptance of wastewater by Solvay. It can be noticed that for both these contaminants there are numerous values exceeding the thresholds. This is important because when this happen Solvay could refuse to use the wastewater coming from Aretusa and this means that fresh water will be consumed instead.

Finally, the effluent loads and concentration are reported in the table below.

Table 6: Effluent concentration of Aretusa

DATA	Effluent concentrations				
	Chlorides	COD	NH4	Ptot	TSS
	mg/l	mg/l	mg/l	mg/l	mg/l
gen-18	596	16	0		10
feb-18	488	18	0		10
mar-18	1140	23	0		10
apr-18	347	21	0		10
mag-18	414	14	0		10
giu-18		19	0		
lug-18	552	20	7		10
ago-18	588	23	9		10

set-18	476	19	0		10
ott-18					
nov-18	520	26	9		18
dic-18	1647	24	5.		10
gen-19	256	21	1		10
feb-19	958	27	3		10
mar-19	689	23	0		10
apr-19	418	21	0		10
mag-19	470	21	0		10
giu-19	577	29	0		10
lug-19		22	1		
ago-19	527	20	0	4	10
set-19	336	24	0		
ott-19		18	0		
nov-19		19	0		
dic-19		17	0		
Average value	**611**	**22**	**2**	**5**	**10**
Deviation	**334**	**4**	**3**		**2**

Table 7: Effluent loads of Aretusa

DATA	**Effluent loads**				
	Chlorides	**COD**	**NH4**	**Ptot**	**TSS**
	kg/d	**kg/d**	**kg/d**	**kg/d**	**kg/d**
gen-18	4231	118	3		71
feb-18	42926	163	4		87
mar-18	99528	204	4		87
apr-18	38813	241	5		111
mag-18	46208	162	6		111
giu-18		211	6		0
lug-18	63285	229	88		114
ago-18	53219	213	88		90
set-18	42427	174	4		89
ott-18					
nov-18	42810	219	76		148

dic-18	143563	214.87	44		87
gen-19	2104	174	15		82
feb-19	8336	241	33		87
mar-19	5499	185	7		79
apr-19	4247	215	5		103
mag-19	5529	250	5		117
giu-19	7636	396	6		132
lug-19		289	12		
ago-19	6558	254	11	57	124
set-19	3908	286	6		
ott-19		217	8		
nov-19		230	7		
dic-19		212	6		
Average value	**34'491**	**222**	**20**	**57**	**96**
Deviation	**38612**	**55**	**27**		**32**

4.2. Life Cycle Assessment results

After the flow analysis for each plant at prior and post stages as well as the influent and effluent flow characteristics, there needs to be a LCA technique procedure to be applied for the distinguished differences to be spotted and presented.

The Umberto model was lunched in order to define the impact of Aretusa's plant. The three main aspects considered in the analysis are the Electricity consumption, the sludge treatment and the final discharge.

For what concern the first point, since the actual value of consumption were not available, a literature research was performed, as reported previously.

The sludge of Aretusa should be a chemical sludge produced with the flocculation phase and removed via the sedimentation process. At the moment, no chemicals are used in the plant so the production of sludge is very low. As it can be seen from Figure 36, the impact of the sludge treatment is more of an auxiliary aid. The figure, in particular, represents the total impact of Aretusa in terms of the following categories:

- Electricity production for the coagulation and flocculation section;
- Electricity production for the equalization phase;
- Sludge treatment;
- Electricity production for the disinfection phase.

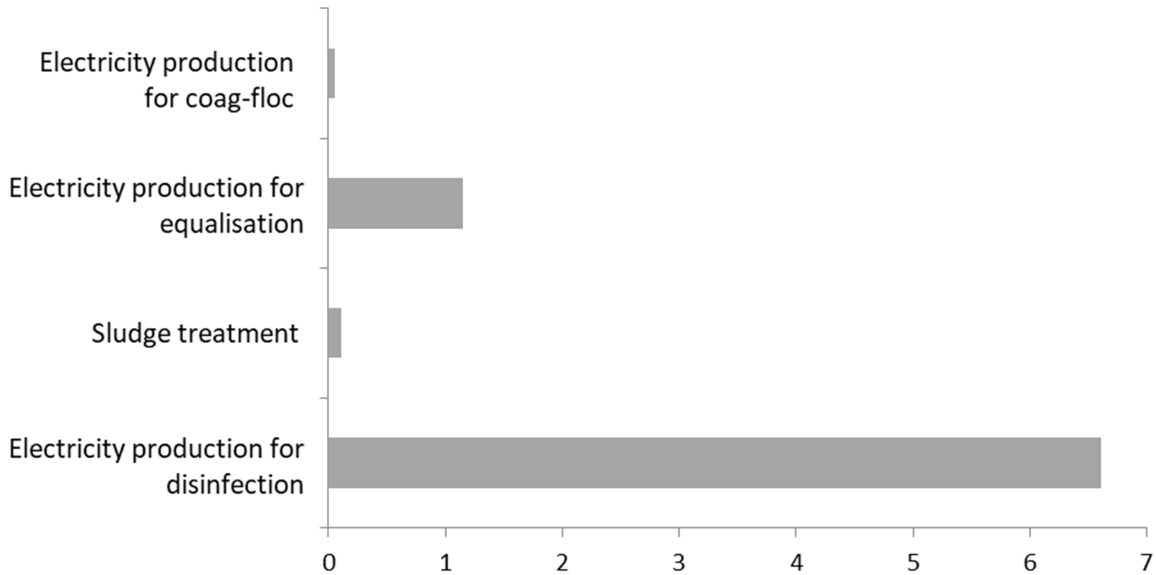


Figure 36 Aretusa process-specific general impacts

As the Figure 36 indicates, the main impact is produced by the electricity production in the disinfection unit. This is due to the higher consumption of the UV disinfection section.

This first result addresses the general impact of the different unit of the plant and so is the same for both the scenarios analyzed. In the following paragraph specific results in terms of final discharge are going to be presented for the two scenarios.

4.2.1. Results of the Scenario 1

Post analysis indicators including the favored parameters and spheres of the study (eg. Climate change and Eutrophication) are shown and compared with their corresponding values as of the other scenario. In the first scenario the wastewater of Aretusa was considered to be discharged in in surface bodies. This scenario was analyzed to highlight the importance of this relationship that allow a reduction of the final impact (as will be shown in the following graphs). This is important because, as already mentioned, in order for the Symbiotic relationship to be successful, Aretusa has to provide specific quality standard of the effluent quality and, when those standards are not respected the wastewater will be discharged in surface bodies with consequent impact. The figure below (Figure 37) shows the total impact for each phase introduced in Umberto software. In particular the focus is on the phase 7 which represent the final discharge. In this case the total impact is 16.94%.

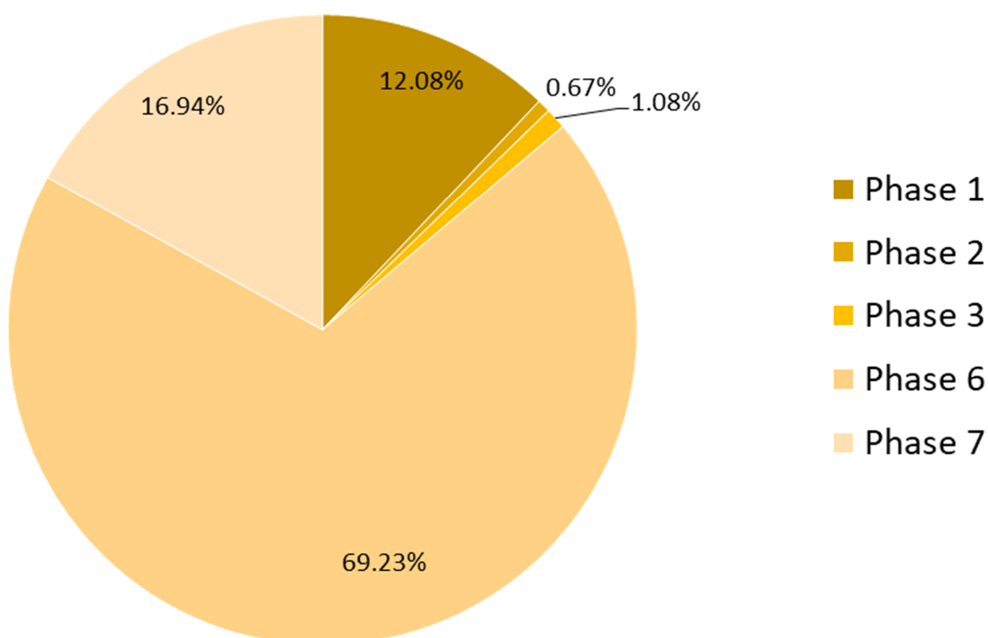


Figure 37 Scenario 1 total impact by treatment stage

Analyzing the specific impact categories (Figure 38) is possible to notice that the main impact is connected with Climate change, Fossil depletion and Marine eutrophication.

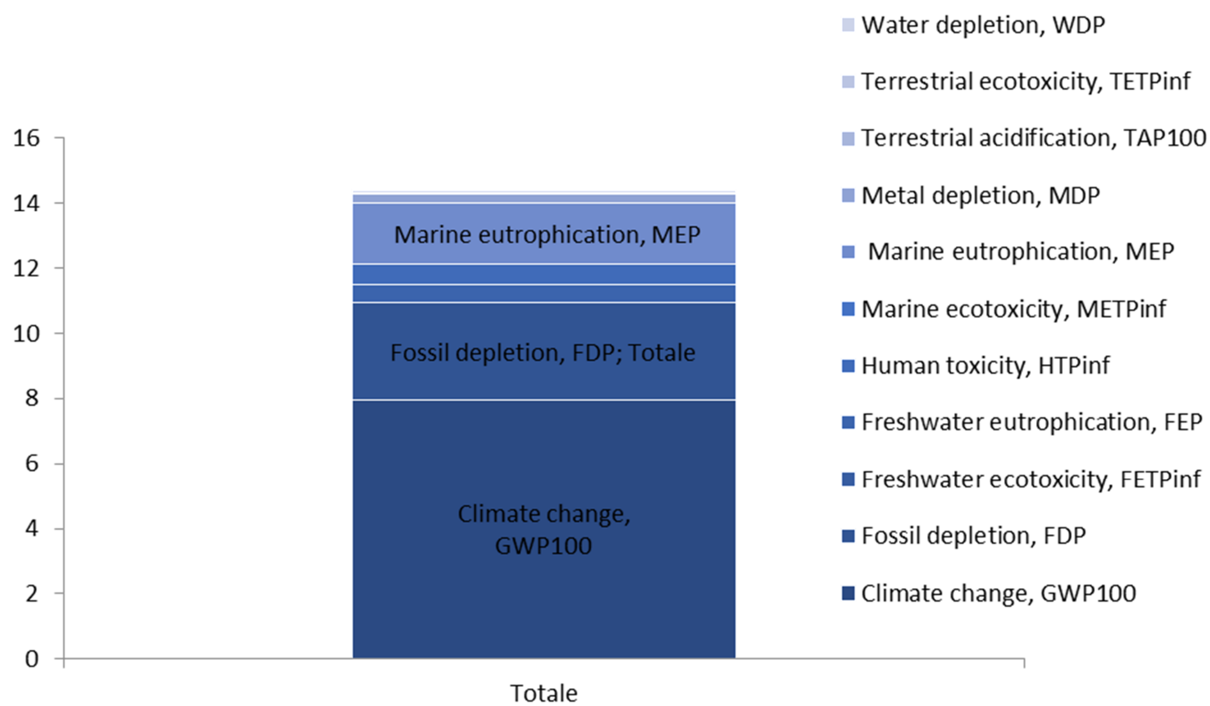


Figure 38: Total impact of each category

Considering the impact of these three categories for each phase (Figure 39) it is evident that phase 6, which is the disinfection phase, has the highest impact in terms of both Climate change and Fossil Depletion. For what concerns Marine eutrophication, the impact is connected only with phase 7 which is the final discharge of the plant. Releasing nutrients in surface water bodies, in fact, have a negative impact for the ecosystem of the water body.

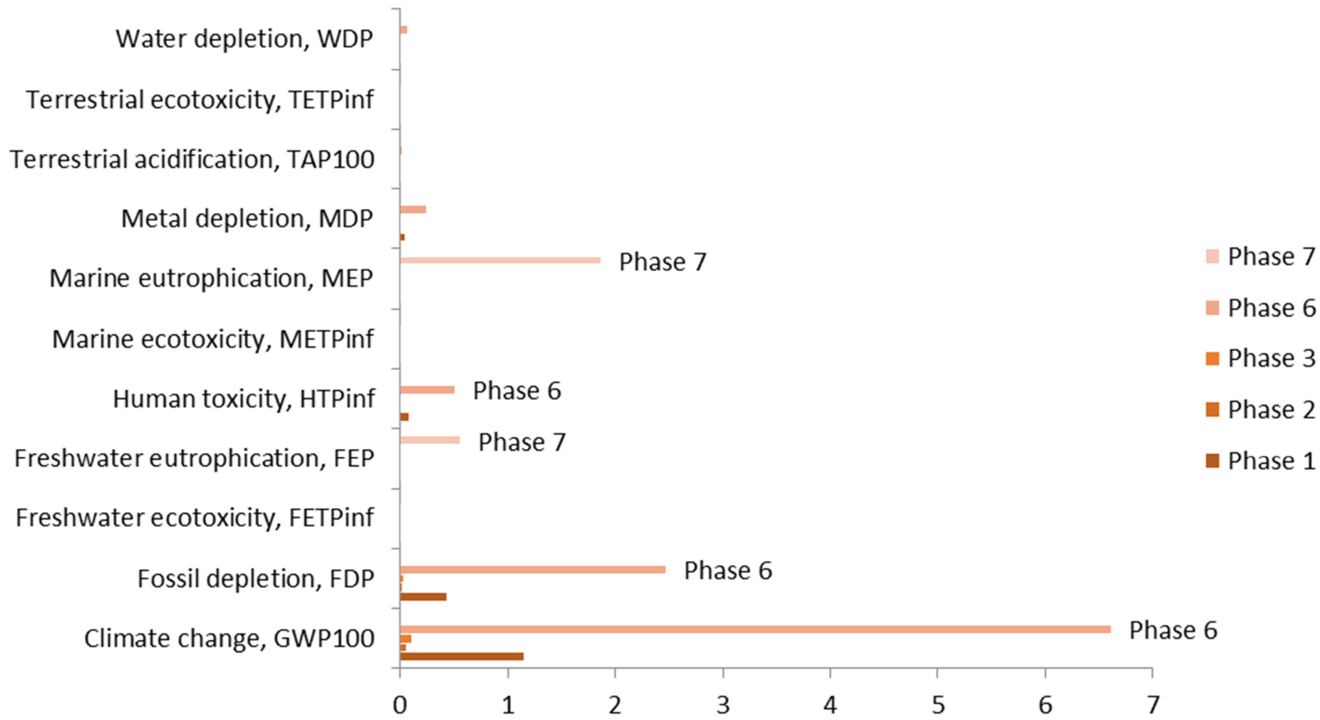


Figure 39 Categories distribution among the phases

4.2.2. Results of the Scenario 2

The same elaborations were done also for the second scenario where the simulation provides for the reuse of Aretusa effluent from Solvay. In this case, as can be noticed by Figure 40, the impact of phase 7 is a negative value. This means that delivering the wastewater to Solvay produce a reduction of impact.

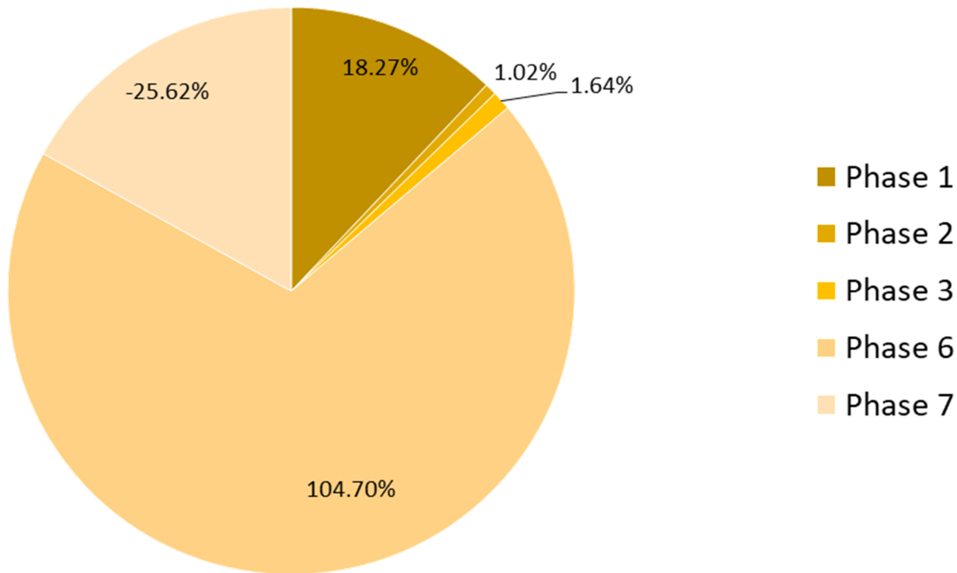


Figure 40: Scenario 2 total impact by treatment stage

Analyzing the specific impact categories (Figure 41 and Figure 42), it is obviously noted that, the main impact along with first scenario correlates with Climate Change and Fossil depletion that are mainly related with the disinfection phase. The major difference is centrally at the eutrophication impacts, represented by a negative value meaning the avoided impact related with the discharge of nutrients in surface water bodies.

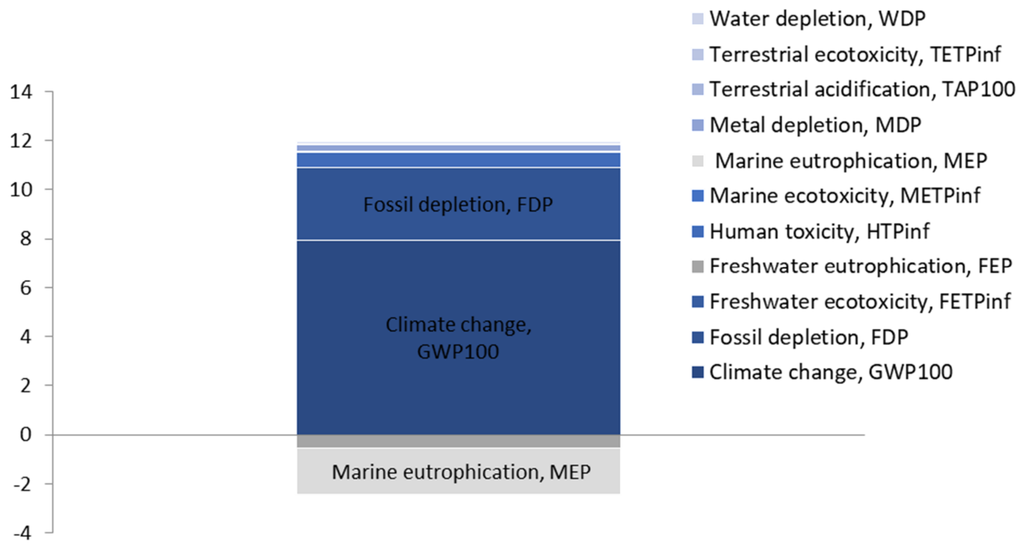


Figure 41 Scenario 2 impacts proportionality

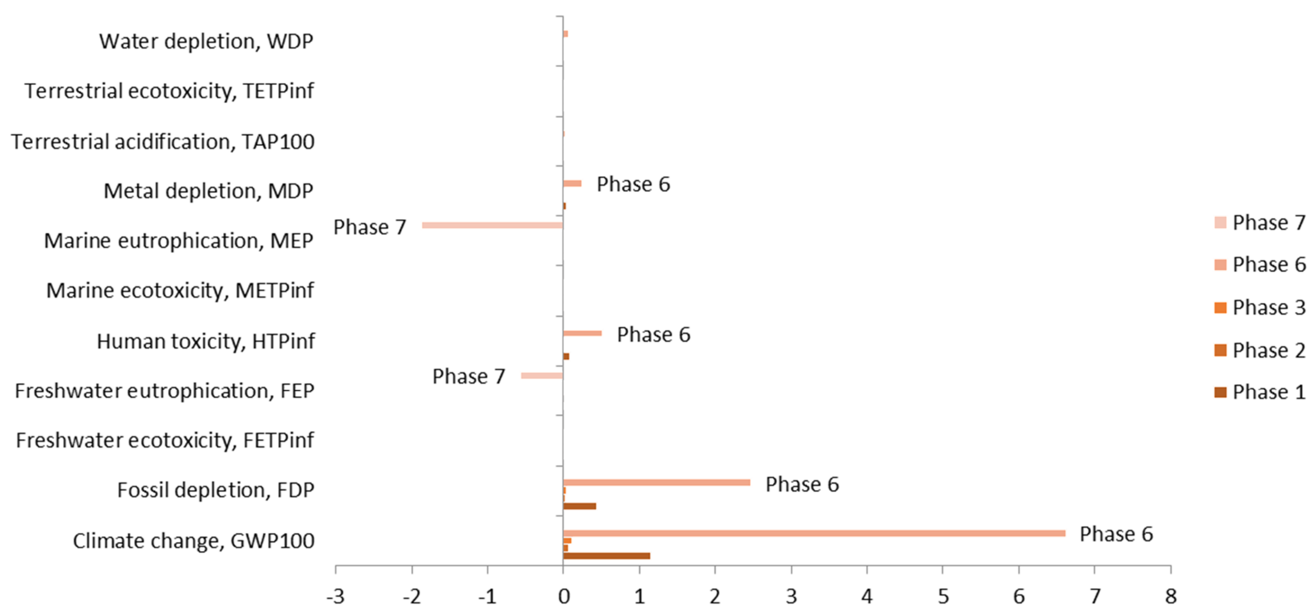


Figure 42 Scenario 2 Umberto software impacts by treatment phase

5. CONCLUSIONS

The present study consisting of four separated and inter-linked chapters was to elaborate in details on the focal points mainly enlisted in “The state of the art” chapter including Zero Liquid Discharge plants with the epitome study on Ultimate project with main and major priorities enlisted as the following subsections (eg. Ultimate project objectives). The Italian case of Aretusa plant as a recovery plant was put into discussion from various aspects of consideration through a full bundle of scientific “methods and materials” as aforementioned.

A literature review was performed to support the approach sufficiently and scientifically a series of quantitative data extracted from papers with the most recent and highest degree of relevance were referenced with the core extracts as shown and presented along with the current study. The economic aspects of different and varied configurations of ZLD and MLD approaches were brought to the scope of this study with concise but effective data to support and corroborate the substantiality of the study with the depth and complexity of academic researches done thus far in the fields relevant to this area of interest. In particular Industrial Symbiosis approach implies the beneficial inter-dependency between the industries with the core goal of minimal freshwater utilization and circularity of water and energy loop.

In this context, the case of Aretusa is a perfect example of a successful symbiotic system. The recovery plant of Aretusa receives the merged influent from two municipal wastewater treatment plants namely Cecina and Rosignano in order to make the water reusable by the industrial partner Solvay. The system was analyzed starting from the three WWTPs involved. In particular, a critical analysis of both quantity and quality of wastewater was performed. The main results from this analysis are:

1) In terms of quantity, the effluent of Rosignano has the main influence, representing almost 70% of the total inflow at Aretusa.
2) The COD and TSS concentration entering Aretusa in 2018 were very high (up to 150 mg/l for COD and 70 mg/l for TSS) due to the high concentration of the effluent of Rosignano. In 2019 there was a great reduction of the concentrations with much lower values for both the pollutants.
3) For what concern nutrients the ammonia concentrations entering Aretusa are very low, with an average value of 2.8 mg/l. For the Phosphorus a concentration of 1.9 mg/l was calculated as influent of Aretusa and this value is mainly influenced by the higher concentration of Cecina effluent.
4) For what concern chlorides influent at Aretusa, a wide variability can be observed with concentration varying between 300 mg/l and 700 mg/l.
5) Finally, a specific comparison between Aretusa effluent and Solvay acceptance limits was performed highlighting some criticism for both COD and Chlorides that have numerous values exceeding the thresholds.

In the second part of the work a deepen analysis on the symbiosis was performed. The Italian case of Aretusa, indeed, is an epitomic example of Industrial Symbiosis and the beneficial linkage and interdependency was introduced, elaborated and analyzed with the best state of convenience of data from the plants measurements. However, some literary values had to be involved for coincidental gaps amongst the collected data. To maximize the resolution through the quantitative approach of Life Cycle Assessment, an analysis was run by the software "Umberto" which necessitated an inventory of data required (eg. fuel, electricity, chemicals and emissions data). The LCA section was to differentiate the two defined scenarios being set to the discharge to the water body or as the influent of Aretusa as the recovery plant and the sequential outflow to the industrial reuse. The outputs from Umberto software as figures mentioned within the subsections of each scenario to clearly distinguish the prevention of the environmental impacts with the ZLD approach being implemented.

Through this LCA analysis it was possible to understand the impact of the Aretusa plant in terms of energy production, sludge treatment and final discharge. What was find out was that sludge treatment has a negligible impact connected also with the minimal amount of sludge produced. For what concern Energy the most impacting phase of the plant is the Disinfection process. Finally, the main focus was the analysis of the discharge impact. Specifically, the two different scenarios created in Umberto highlighted how a successful symbiotic relationship between the industrial partner and the water utility allow a reduction in terms of impact of 25%.

This was just a preliminary study in order to underline and quantify the positive impact of the symbiotic relationship of Aretusa. This analysis could be implemented including, for example a study on how Solvay uses the water coming from Aretusa in his process and how this avoids consumption of fresh water.

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