Circular Economy and the local closure of the urban water cycle. Case Analysis.

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Abstract: Water is currently considered a scarce natural resource that needs to be preserved, therefore it is necessary to adopt measures that promote the efficient use of water and the potential reuse of locally treated wastewater. This is how the concept of circular economy emerges.

The efficient use of water is addressed in this dissertation in a set of three water treatment options for subsequent reuse. In the first option a drainage network was created with the destination a WWTP, and the effluent is stored. The second option consists in the division of the urban area in "neighborhoods", creating for each "neighborhood" a drainage network directed to a compact WWTP. The third option is a micro-scale option to treat grey water separately from black water.

An analysis was carried out not only the economic viability of each option by estimating the associated costs and determining economic indicators, but also their sustainable contribution.

In option 1 the estimated result after 25 years is more than 14 million euros. For option 2 the result is almost 8 million euros. Finally, option 3 has a result of approximately 3 million euros. In terms of sustainability, both option 1 and 2 are efficient (A+) while option 3 is less efficient (C).

Finally, a sensitivity analysis was carried out on the results obtained, in order to allow a better appreciation of the results, showing that both options have potential for application.

Keywords: Water scarcity; Circular economy; Efficient use of water; Economic viability; Sustainable contribution.

1. Introduction

As water is the planet's most valuable natural resource, its conservation is one of the most important pillars of sustainable development (Monte & Albuquerque, 2010).

Nowadays, due to growing global concerns about population growth, climate change, the use of natural resources and the way they have been exploited, the sustainable management of water resources has gained significant relevance, which implies the conservation of these same resources, including, therefore, the reuse of wastewater (Nacional, 2019).

In Portugal, the need for sustainable water management has already been confirmed as a national priority through the National Plan for the Efficient Use of Water (NPEUW), whose main objective is to promote the efficient use of water, encouraging the development of a new water culture, contributing to the preservation of the natural environment, keeping in mind sustainable development and respect for future generations (APA, 2001).

Water reuse is the use of treated wastewater for any purpose which is of socio-economic benefit. The concept of water reuse is therefore perfectly synonymous with the use of treated wastewater. Water can be reused multiple times and for different purposes, always corresponding to the use of water which has become wastewater and which generally undergoes treatment (Monte & Albuquerque, 2010).

The conservation of natural resources and the efficient use of water are national objectives with great relevance for public water supply and urban wastewater sanitation services. However, there is no generalized practice of urban wastewater use in Portugal, even in regional contexts of greater water scarcity (Monte & Albuquerque, 2010).

The possibility of treating and reusing these same wastewaters on an urban scale, emerges as an option to close the water cycle and, therefore, create a circular economy logic whose purpose is to rethink more than just its resource footprint and energy efficiency, which in turn is closely related to water efficiency (AICEP, 2021).

Closing the water cycle leads to greater efficiency in its use, as well as a substantial reduction in waste, making production and consumption self-sustaining. In other words, water is reused instead of being discarded, and recycled water is used instead of repeated abstraction of this scarce resource, therefore, contributing to sustainable development (AICEP, 2021).

In cities, the environmental consequences are not evaluated in relation to the form of soil occupation, contributing to an unbalance of the hydrological cycle in relation to the increase in the share of surface runoff and the reduction in infiltration. Therefore, the concept of urban metabolism becomes relevant, a term defined by Girardet (1998) to describe the relation between the natural and anthropic environments. Two models synthesize this concept of urban space: linear and circular metabolism/economy.

The linear economy translates the constant way we build cities with repeated consumption of natural resources and production of waste, while the circular economy considers that the input of natural resources and output of waste occurs to maximise reuse and recycling processes, through solutions that resemble the natural behaviour of the environment.

The implementation of circular economy aims to reduce the ecological footprint. Regarding urban infrastructure systems, more specifically drainage techniques, linear economy is called traditional or grey drainage and circular economy is called sustainable or green drainage.

As mentioned above, the growing concentration of population in cities and the absolute need for water for human consumption, economic activities, and ecosystems, require a global consideration of the urban water cycle, due to the pressure it is under, which influences policies at the local level to ensure the sustainability of urban life.

That said, the need to move towards a circular economy through the efficient use and management of natural resources becomes imperative.

2. Circular economy and closing the water cycle

2.1. Water on planet earth

Water is one of the most important substances that exist because it is indispensable for living beings.

Most living organisms use it in liquid form to carry out various biological processes. The availability of this scarce resource is fundamental to the well-being of the world, and the water cycle is the engine of all life on Earth.

Water covers about 70% of the Earth's surface and reaches a volume of 1386 million cubic kilometres. However, the amount of fresh water available for human use is limited by the planet's natural conditions. In fact, only 2,5% of all water on Earth is freshwater, the rest being salty (most of it is found in the oceans) (Thomas, 1994).

Of this 2,5%, most (1,8%) is retained in the form of ice in the Antarctic, the Arctic and glaciers, and is not available for human use (Thomas, 1994).

Figure 2.1 shows the global distribution of water on planet Earth.

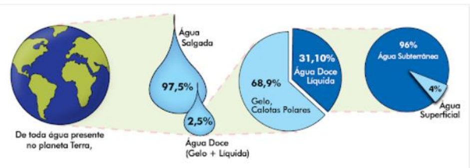

Figure 2.1 – Global distribution of water on Planet Earth (Source: Alcantara (2021))

As mentioned above, water is the only substance that exists in nature in all three states (solid, liquid and gaseous) and circulates in a continuous movement from one state to the other. This variation is due to the existence of what we call the "Water Cycle".

The water cycle feeds life on Earth and provides living things with freshwater to produce ecosystem goods, such as all the biomass produced to design food, fibre, fuel, biodiversity, habitats for aquatic species, carbon capture and storage services, climate regulation, and water for domestic and industrial use (Rockström et al., 2009).

As mentioned above, freshwater, in quantity and quality, is essential for all aspects of life and for economic and social development, specifically for health, job creation and poverty reduction (Costanza & Daly, 2007). Therefore, water resources are fundamental to all economic activities, including agriculture, industry, energy production and environmental protection.

But water is not equally available to all countries. Figure 2.2 shows the variation in freshwater distribution across continents.

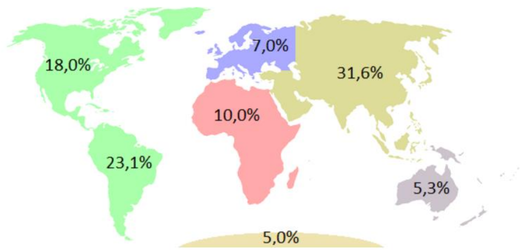

Figure 2.2 - Distribution of freshwater across continents (Source: Khan Academy (2021))

2.2. Water scarcity in the world

According to the United Nations, the scarcity of this universal good tends to increase until 2050 thanks to demand from the industrial and domestic sectors of emerging economies and thanks to the increase in world population. Therefore, there is a growing need to balance the demand for water resources with the needs of communities.

This scarcity can be physical (lack of water of sufficient quality for human use), economic (lack of adequate infrastructure due to financial, technical or other constraints) or institutional (lack of institutions for reliable, safe and equitable water supply) (Unicef & Inda, 2013).

According to Unicef & Inda (2013), in 2011, 41 countries experienced water problems, with an increase of 5 countries compared to 1998. Of these countries, 10 countries - from the Arabian Peninsula, North Africa and Central Asia - made the withdrawal of more than 100% of renewable freshwater resources.

It is important to mention that, as soon as a country reaches a level of abstraction above 100%, it starts to deplete its renewable groundwater resources and must rely on non-renewable fossil groundwater or non-conventional water sources such as desalinated water, wastewater and agricultural drainage water (Unicef & Inda, 2013).

Figure 2.3 shows the water stressed regions of the world in 2019.

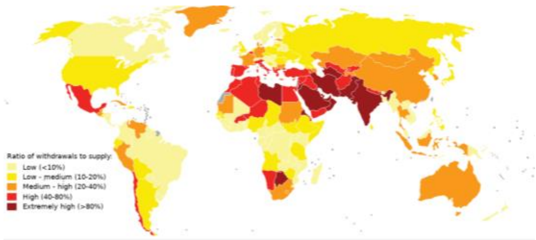

Figure 2.3 - Water stress map in 2019 (Source: Wikipedia (2019))

An analysis of Figure 2.3 shows that the regions with the greatest water scarcity are mostly in developing countries, but it can also be seen that some developed countries face serious problems with climate change.

Considering the problems mentioned above, it is vital to become aware of the problem we all face and to take measures to promote the efficient use of water not only on a macro scale but also on a micro scale.

2.3. Circular economy

Considering what was said above about population growth on a planet with finite resources, the linear economy becomes a risk. Thus, for environmental, social and economic reasons, it is necessary to ensure the growth and development of populations without causing the depletion and degradation of these limited resources.

Consequently, the circular economy model actively promotes the efficient use and productivity of resources, through products, processes and business models based on the dematerialization, reuse, recycling and recovery of materials (República Portuguesa - Ambiente, 2017).

In this economy, materials are preserved, restored or reintroduced into the system in a cyclical manner, creating economic advantages for suppliers and users as well as environmental advantages resulting from reduced extraction and importation of raw materials, reduced waste production and reduction of associated emissions (República Portuguesa - Ambiente, 2017).

At an environmental level, the water sector can be a example of the circular economy in water supply and wastewater and stormwater management services, given more proactive regulation. It can also serve as a response to the challenges of population growth and climate change (República Portuguesa - Ambiente, 2017).

That being said, the practice of reusing treated wastewater emerges as a strategy for sustainable economic development and environmental protection.

2.4. The importance of reusing water

Water reuse is seen as a pillar in the sustainable management of water resources. This reality is recurrent since antiquity (Angelakis et al., 1999), but it is only since the XI century that there have been major developments.

In this way, the use of treated wastewater for non-potable uses, such as irrigation, industry, aquifer recharge or recreational uses, which account for the vast majority of water consumption and whose quality requirements are substantially lower than for water for human consumption, becomes part of a paradigm of sustainability regarding the use of water resources (APA, 2001).

Although approaches based on the concept of wastewater use are still not common in Portugal, there is already a lot of knowledge, discussions and progress about the conservation of natural resources and the efficient use of water.

This is due to the fact that these issues are highly relevant national objectives not only in public water supply and wastewater sanitation services, but also at the political level, because it obliges countries with different development standards to establish minimum environmental protection measures.

As previously mentioned, in Portugal, there is a National Plan for the Efficient Use of Water (NPEUW), which is a national policy instrument for the efficient use of water and has as its main objective the promotion of this appropriate use of water, especially in the urban, agricultural and industrial sectors. It contributes to minimize the risks of water scarcity and to improve environmental conditions in water environments, without jeopardizing the vital needs and quality of life of the populations, as well as the socio-economic development of the country (PNUEA, 2001).

In a circularity logic, today, a new distribution network is being implemented to take high quality water, treated at the AdTA Water Factories, to places with the largest non-potable consumption (for example: irrigation and street washing). This new water product - Water+ (treated wastewater of a quality compatible with non-potable uses, whether agricultural, urban or industrial) - is a sustainable source that is largely independent of climate uncertainty, allowing a reduction in pressure on water resources (Águas do Tejo Atlântico - Grupo Águas de Portugal, 2020).

3. Options for closing the urban water cycle

3.1. Collection solutions

Wastewater collection, in the urban area, is initially carried out through the wastewater drainage building network (Paixão,1999).

The wastewater drainage building network is used to collect and channel wastewater from its origin to public collection systems, which collects wastewater from various buildings and channel it to its final destination, usually a wastewater treatment plant (Ministério das Obras Públicas Transportes e Comunicações, 1995).

In the wastewater drainage building network a separate system is used, consisting of two separate networks, upstream from the connection branch chambers, one intended exclusively for domestic wastewater drainage and the other for rainwater drainage (Paixão,1999).

All domestic wastewater collected at a level no lower than the street level where the public collector is located is drained by gravity. Domestic wastewater collected at a level below the street level, such as basements, must be lifted by pumps (mechanical lifting) to a level at or above the street level, even if it is above the level of the public collector. This is done considering the possible operation of the public collector on load, as otherwise the basements would be flooded (Paixão,1999).

3.2. Drainage solutions

Wastewater is routed to a public wastewater drainage system composed essentially by a network of collectors, treatment facilities (WWTP) and final discharge devices (Paixão,1999).

The implementation of this system is mainly conditioned by the topographical characteristics of the terrain, as the intention is for the drainage to be gravitational, avoiding as much as possible, the installation of lifting systems due to the associated risks and maintenance requirements. Consequently, the system's network sections originate at higher elevations and develop towards lower elevations.

According to the General Regulation on Public and Building Water Distribution and Wastewater Drainage Systems (RGSPPDADAR), wastewater drainage systems are classified as:

- Separate: consisting of two separate networks of collectors, one for domestic and industrial wastewater and the other for rainwater drainage or similar;
- Unitary: formed by a single network of collectors where domestic, industrial and rainwater are collected together;
- Mixed: resulting from a combination of the two previous types, in which part of the network of collectors operates as a unitary system and the rest as a separate system;
- Partial or Pseudo-separative: which allows, under exceptional conditions in old buildings, the connection of rainwater to domestic wastewater collectors.

The type of system most commonly used in the construction of drainage networks for wastewater in new areas to be urbanized in Portugal is the separate system. The joint design of the domestic and industrial wastewater drainage system and the rainwater drainage system is mandatory (Paixão,1999).

3.3. Treatment solutions

Wastewater treatment (grey and/or black waters) can be carried out in various ways, depending on the limitations of space and location, and at different levels of treatment depending on the purpose for which it is intended. They are processed through two main types: WWTP and Phyto-WWTP, however, not all treatment systems are suitable from the economic and functional point of view for small agglomerations or low effluent flow.

All stages of wastewater treatment are described below, according to (DR 23/95, 1995).

- Preliminary: The process of separating the larger waste by means of grids (harrow), sieving and, where appropriate, grease retention chambers (grease removal), sand (desanding) or hydrocarbons.
- Primary: Chemical or physical process involving the decantation of solid particles in suspension and through which polluting matter is separated from the water by physical sedimentation (primary sedimentation). This treatment may be aided by chemical agents that, through coagulation or flotation, allow the formation of flocs of pollutant particles that are more easily eliminated.
- Secondary: Biological process, which may be anaerobic or aerobic, with secondary sedimentation leading to the removal of dissolved or suspended biodegradable organic matter. It can be carried out by activated sludge or biological filters (percolation beds).
- Tertiary: It consists of the disinfection of the water resulting from the previous treatment phase in order to eliminate pathogens, refractory organic compounds and remaining nutrients such as nitrogen and nitrogen. This type of treatment can be done biologically, by the addition of chemicals such as chlorine or iodine and also by ultraviolet radiation (UV).
- Advanced: Elimination of salinity (where applicable).

The WWTPs use physical, chemical and biological treatment. However, with regard to possible treatment systems suitable for small settlements, housing estates, housing developments or others, the compact WWTPs stand out. This type of WWTP stands out for its advantages in terms of ease of installation (prefabricated equipment) and start-up.

1. <u>Compact WWTP:</u>

In this process, in general, after primary decantation, the wastewater goes to the biological reactor where aeration and agitation of the sludge takes place in order to promote the growth of the biomass necessary for treatment. Afterwards, there is secondary decantation of the solid matter in suspension and, eventually, water disinfection.

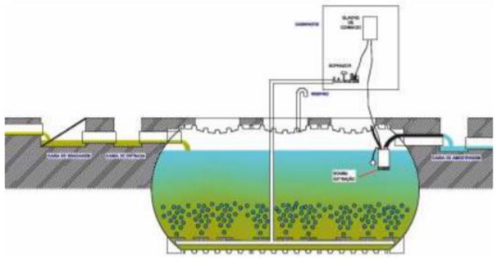

Figure 3.1 - Flow diagram of a compact WWTP (Source: Tubofuro (2021))

Regarding the common treatment of domestic and rainwater, there are authors who argue that water treatment reservoirs should receive domestic and rainwater together on the grounds of large volumes of rainwater in dry seasons, with the system then being fed by grey wastewater (Mendes, 2011).

2. <u>Phyto-WWTP:</u>

Natural level treatment systems, also known as Phyto-WWTP are biological treatment plants for effluents, designed to take advantage of specific characteristics of natural wetlands in order to improve the treatment capacity of wastewater (Mendes, 2010).

Of the most common types of Phyto-WWTP, the sub-surface horizontal flow is the most widely used (Mendes, 2011).

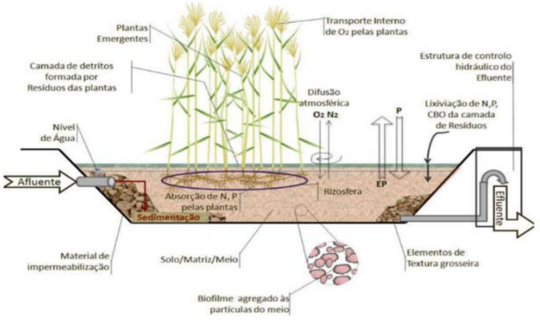

Figure 3.2 - Sub-surface horizontal flow Phyto-WWTP (Source: Treatment, n.d.)

3.4. Storage solutions

With a view to the reuse of treated wastewater, the use of a treated wastewater storage system (TWSS) is advised to reserve treated effluent at the WWTP during the day, which will only be distributed during short periods of the day for various activities mentioned in the following section (Monte & Albuquerque, 2010).

The classification and respective hydraulic sizing of the reservoirs follow the rules used for drinking water storage reservoirs and established in the Regulatory Decree n. º 23/95 of 23rd of August.

Operational storage consists of guaranteeing volumes of water to be able to compensate for the fluctuation in hourly demands throughout the day and from day to day, this storage being similar to a regularization flywheel in water distribution systems. In addition, it must allow for the proper functioning of the distribution and application networks, the regularization of pumping operations, the balancing of piezometric loads and reserves for emergencies (Monte & Albuquerque, 2010).

These types of tanks, as they contain non-potable water, must be closed and must be properly marked (Monte & Albuquerque, 2010).

Sometimes in the use of these reservoirs, some problems are generated, such as: immobilization of the effluent, loss of chlorine inserted in the treated wastewater to ensure its quality, among others, and should be controlled. Therefore, strategies should be adopted to minimize these problems or even solve them.

The most effective solution to the problems mentioned above is the application of an aeration system, which solves not only the problem of the lack of oxygen (maintaining aerobic conditions), but also the problem of thermal stratification.

3.5. Recycling and reuse solutions

After the wastewater has been treated, in order to be successfully reused, it must have quality characteristics that satisfy its intended use, minimizing any adverse environmental impact and not contributing to health risks for those exposed (workers in the re-use systems, users of the re-used water, general public) (Monte & Albuquerque, 2010).

In Portugal, the most likely solutions of interest for water reuse (after being properly treated and becoming treated wastewater) are irrigation in agriculture; landscape irrigation, including the irrigation of golf courses (so important in the country's touristic and socio-economic panorama); the supply of some industries, such as textiles and paper, with a significant dimension in the Portuguese industrial fabric; the recharge of aquifers; some environmental and landscape uses, such as the creation of recreational lakes to preserve wildlife habitats; as well as several urban uses that do not need to use treated water for human consumption, such as washing streets, flushing toilets, fighting fires (Monte & Albuquerque, 2010).

3.6. Distribution solutions

The distribution systems for treated wastewater for reuse must be constructed and sized like a water distribution network for human consumption, on the basis of peak hourly flows, with storage volumes estimated according to needs (Monte & Albuquerque, 2010).

The treated wastewater distribution networks are specific networks, whose layout is defined according to the points of consumption and must contain measuring instruments in order to control the treated wastewater and prevent the misuse of these networks by the population and the contamination of the water supply networks for human consumption. It should be noted that, in these networks, there must be control of retention time, so that there is no deterioration of water quality.

The identification of the pipes of the treated wastewater distribution network must be clear, and when planning this network, the remoteness of these pipes with different existing networks and the limitation of access to the treated wastewater distribution network must be considered.

Both the pipes and fittings of treated wastewater distribution networks must be clearly identified with a designation of the liquid they carry, and must be of a different color from that of drinking water pipes (Monte & Albuquerque, 2010).

In the USA, the color used in this type of network is purple, so for the sake of standardization, in Portugal it is recommended that the same color should be adopted for the piping of reusable water distribution systems (Monte & Albuquerque, 2010).

Figure 3.3 - Example of identification of treated wastewater distribution pipes

4. Case Studies: Local Solutions

4.1. Loures

The municipality of Loures, with an area of 168 km^2 and around 200 thousand people, is constituted of ten parishes, namely: Union of parishes of Camarate, Unhos and Apelação, Union of parishes of Moscavide and Portela, Union of parishes of Sacavém and Prior Velho Union of parishes of Santa Iria de Azóia, São João da Talha and Bobadela, Union of parishes of Santo Antão and São Julião do Tojal Union of parishes of Santo António dos Cavaleiros and Frielas and parishes of Bucelas, Fanhões, Loures and Lousa (CMLoures, Município).

Figure 4.1 illustrates the geography of the municipality of Loures.

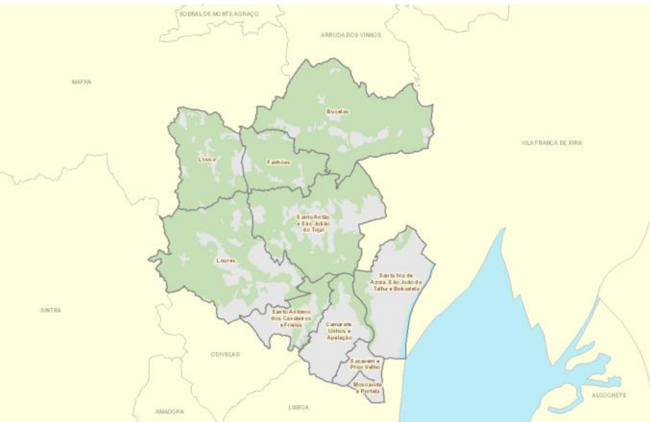

Figure 4.1 - Geographic map of the Municipality of Loures (Source: CMLoures (2020a)).

Regarding the use and occupation of land in the municipality of Loures, most of the territory is natural areas, specifically agricultural areas (25,6%), forests (17,1%) and bushes (16,7%). Regarding the artificial territories, which include all the built fabric for housing, industrial and commercial spaces, infrastructures and equipment, these occupy about 28% of the municipality (IST, 2021).

Most of the artificial territories are concentrated in the south, namely in the parish unions of Moscavide and Portela; Sacavém and Prior Velho; Santa Iria de Azoia, São João da Talha and Bobadela; Camarate, Unhos and Apelação; Santo António dos Cavaleiros and Frielas; and Loures, which are the most densely populated parishes (IST, 2021).

Regarding the interveners in the water cycle in the Municipality of Loures, the Intermunicipal Water and Waste Services of Loures and Odivelas (SIMAR) is the company that manages the supply and drainage systems and Águas do Tejo Atlântico, S.A. that manages the wastewater transport and treatment systems (IST, 2021).

These companies operate with Loures Municipal Chamber, which plays an important role in all areas of the municipal water cycle.

Considering the growing demands of consumers, the Municipality has invested in the last decade in increasing the water supply network, increasing its coverage, currently with a coverage rate of 100%. In addition, the Municipality's main goal is to increase the water reservoir capacity in order to be able to guarantee a better response to customers in case of supply disruption by suppliers (IST, 2021).

4.2. Santa Iria de Azóia (study area)

The growing pressure on water masses and the occurrence of periods of water scarcity, with times of prolonged drought, reinforce the need to seek alternatives that are more environmentally appropriate and financially attractive. Coincidentally, some municipal management entities and with a concentrated focus on the environment and sustainability intend to invest and work on measures that benefit a circular economy of valorization and environmental protection.

The main objective of this case study is to analyze three domestic wastewater treatment options in order to enable its reuse in a highly populated area, promoting the closure of the urban water cycle and thus enabling the circularity of water. This study aims to explore which option is the most advantageous, not only through an analysis of economic viability but also through the analysis of its sustainable contribution.

The study area is located in the parish of Santa Iria da Azóia, which belongs to the municipality of Loures, and has about 1.66 km^2. In what concerns the use and occupation of the soil, in this area, most of the territory is artificialized territory, in which all the built fabric related to housing, industry and equipment space is inserted.

Option 1 provides solutions for drainage, treatment and storage of domestic wastewater in the area to be treated. Therefore, in this solution, a drainage network was created in corrugated PVC SN8, DN200 and DN250, with 11,84 km, in order to drain all the domestic wastewater from the area to the WWTP with capacity for 5000 e.p.. The Wastewater Treatment Plant consists of three treatment lines. The first consists of treatment of the liquid phase (preliminary treatment and equalization, secondary treatment and tertiary treatment). The second treatment phase refers to the treatment of the solid phase (sludge treatment). Finally, the last treatment line concerns deodorization. After being treated, the water is stored in a reservoir with the capacity to store the volume of domestic wastewater in the area and also possible rainwater infiltration.

Table 4.1 - Estimated population, average daily flow and peak flow in Study area (option 1)

Year	Pop	Average daily flow (m^3/day)	Peak flow (m^3/day)
0	4 019	578,71	1 995
HP	5 000	720,00	2 411

Option 2 involves dividing the addressed area into zones (a total of seven zones) and analyzing the treatment of domestic wastewater on a neighborhood scale. In other words, a drainage network was created in corrugated PVC SN8 and DN200 for each of the zones, assigning them compact treatment plants with the capacity to treat the effluents from each zone. In this option the placement of storage tanks for purified water was not considered since it is assumed that the water after being treated at the WWTP is automatically directed to the treated wastewater distribution network.

Table 4. 2 - Estimated population, average daily flow and peak flow in the zones (option 2)

Zone	Area (km^2)	Year	Pop	Average daily flow (m^3/day)	Peak flow (m^3/day)
1	0,12	0	602	86,69	298,77
		HP	735	105,83	354,37
2	0,06	0	495	71,28	245,66
		HP	604	87,02	291,38
3	0,04	0	988	142,27	490,33
		HP	1206	173,68	581,59
4	0,07	0	400	57,60	198,52
		HP	418	60,19	201,55
5	0,09	0	295	42,48	146,41
		HP	524	75,46	252,67
6	0,11	0	804	115,78	399,02
		HP	982	141,34	473,28
7	0,07	0	435	62,64	215,89
		HP	531	76,47	256,06

Finally, option 3 corresponds to a micro-scale option, analyzing a row of six buildings, if aims to separate grey water from black water, as these are waters that require different treatments. Therefore, this option consists of the implementation of corrugated PVC collectors SN8 and DN200 from the manhole to, in the case of grey waters, a domestic soapy water purifying station of low contamination and with a capacity of 160 e.p. In the case of black waters these were routed to a Phyto-WWTP with the same capacity.

Table 4. 3 - Estimated population, average daily flow and peak flow for micro-scale option (option 3)

Year	Type of waters	Pop	Average daily flow (m^3/day)	Peak flow (m^3/day)
0	Grey	90	10,38	35,76
	Black		2,59	8,94
HP	Grey	160	18,43	61,72
	Black		4,61	15,43

In order to be possible to determine the sustainable contribution for the three options (analyzed in section 5.2.) it is necessary to study, only in quantitative terms, the water need of the area to intervene, because it is admitted that, in qualitative terms, the water to be used respects the classification of NP 4434:2005.

Having said this, it is important to mention that the analysis will be carried out only during the summer months (150 days), since it is in the summer that the greatest periods of drought occur, and water requirements are higher.

Knowing that in the intervention area the necessary flow for irrigation, in the summer months, is 3,5 l/m^2/day and for street washing is 0,017 m^3/m^2/day (IST, 2021), it was estimated that the study area required 2 688,71 m^3/day and 1 734,88 m^3/day, respectively.
Considering that summer corresponds to 150 days, 403 306,42 m^3 for irrigation and 34 697,65 m^3 for street washing would be necessary to satisfy the water needs. It should be noted that in the case of street washing it was assumed that the streets would be washed once a week during the summer season (20 days).

Therefore, the total volume of purified water required for reuse in irrigation and street cleaning in the area to be treated is 438 004,06 m^3.

5. Viability Analysis

5.1. Economic

In this case study, the analysis will be carried out for the three options, in order to compare which is the most beneficial in economic terms. This comparison will be made, in a first phase, using the accounting method involving Cash Flows created by costs and revenues and, in a second phase, using the economic analysis with the help of the IRR tool of the Excel software. Finally we will verify the point at which there is a break-even investment.

This analysis, since it is a very high investment in economic terms, cannot be made only for a short period of time. Consequently, and considering the construction periods and the usual maintenance periods for this type of solution, it was decided that the analysis will be carried out over 25 years.

In addition, the effect of inflation was disregarded in this analysis, considering a real discount rate with Cash Flows at constant prices. The discount rate used in this study was 6% (Mendes, 2011).

The costs considered include all costs of construction, maintenance and operation of the infrastructure envisaged for each of the options, excluding fixed costs for any of the options, such as initial investments with the landscape irrigation system, street washing and associated maintenance.

After performing the accounting method, which involves the Cash Flows created by costs and revenues, the following results were obtained, over the 25-year analysis period.

For option 1, the final value of accumulated NPV is positive, therefore the option has a positive result of more than 14 million euros after 25 years.

In order to analyze the attractiveness of this option, the IRR (internal rate of return) was calculated and it was found that, for the adopted revenue (0,70 €/m^3 of purified water), the IRR is 15%. Considering that the IRR analyzes the attractiveness of a particular venture, the higher the IRR value, the more attractive is the business, although a positive IRR is already a sign of profit in the business. Therefore, this option is quite viable economically.

Finally, Figure 5.1 shows that the break-even point, the point at which the option costs equal revenues, occurs between years 8 and 9.

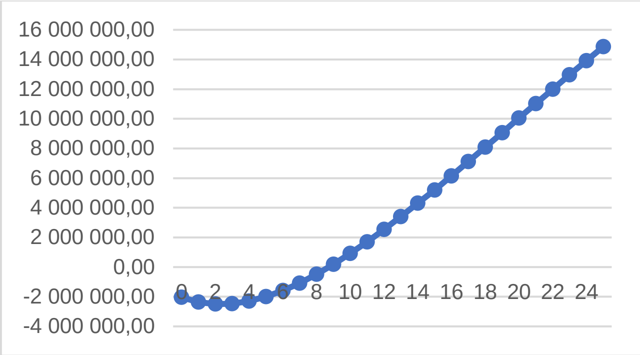

Figure 5. 1 - NPVs accumulated for option 1

For Option 2, the final value of accumulated NPV is positive, therefore the option has a payout of almost 8 million euros after 25 years.

The attractiveness of this option was analyzed by calculating the IRR and it was found that, for the revenue adopted, the IRR is 7%. Therefore, it was found that this option is economically viable.

Figure 5.2 shows that the break-even point, the point at which the option's costs equal the option's revenues, occurs between Year 15 and Year 16.

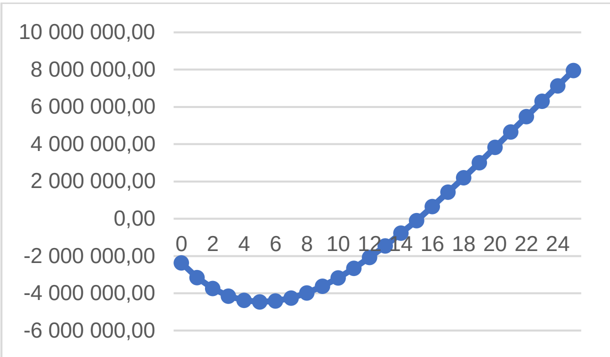

Figure 5. 2 - NPVs accumulated for option 2

In Option 3, the final value of accumulated NPV is positive, therefore the option has a positive result of approximately 300 thousand euros after 25 years.

The IRR was calculated, and it was found that, for the adopted revenue, the IRR is 6%. Although the IRR of this solution is the lowest, it is viable in economic terms.

Analyzing Figure 5.3, we observe that the break-even point, the moment from which the option's expenses equal the option's revenues, occurs between years 15 and 16.

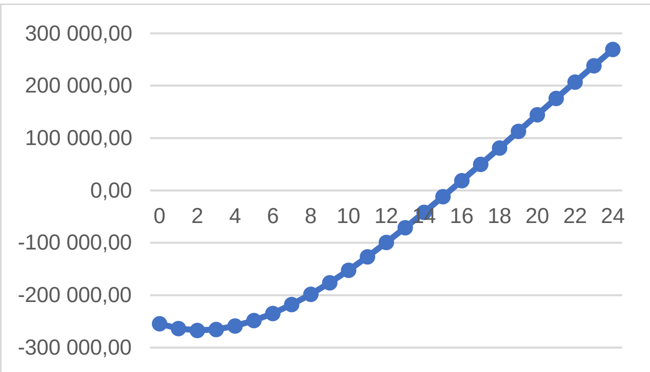

Figure 5. 3 - NPVs accumulated for option 3

5.2. Sustainability contribution

In Portugal, the LiderA system (Lead by Environment) was introduced by Manuel Duarte Pinheiro, PhD in Environmental Engineering. This system consists of repositioning the environment in construction, from the point of view of sustainability, assuming itself as a "system to lead by the environment" (Pinheiro & Nunes, 2011).

The performance levels considered in this system indicate whether the solution is sustainable or not. These levels are configured through either the improvement of the existing practices or the reference to good practice values, as it is usual in international systems. From the communication point of view, the performance levels, although numerical, are transformed into classes (from G to A+++) (Pinheiro & Nunes, 2011).
In Figure 5. 4 it can be seen that the levels vary from the least efficient (G) to the most efficient (A to A++).

Figure 5. 4 - Levels of sustainability performance (Source: (Pinheiro & Nunes (2011))

Table 5. 1 - Sustainable contribution for each study option

Option	Sustainable Contribution (SC)
1	A+
2	A+
3	C

6. Results Discussion

6.1. Circularity analysis

The comparison of the values for the different study options are summarised in Table 6.1 and Figure 6.1.
In order to be able to compare the three options, in option 3 the costs determined, of economic viability analysis, in chapter 5.1 were increased by factor of 10.

Table 6. 1 - Results of the three options analyzed

Option	NPV (€)	IRR (%)	SC
1	14 861 540,67	15	A+
2	7 957 208,62	7	A+
3	2 547 282,98	6	C

Looking at Table 6.1, circularity is possible for all options, as the IRR is positive for options 1 and 2, with Option 3 (micro-scale) being the least viable due to its sustainable contribution.

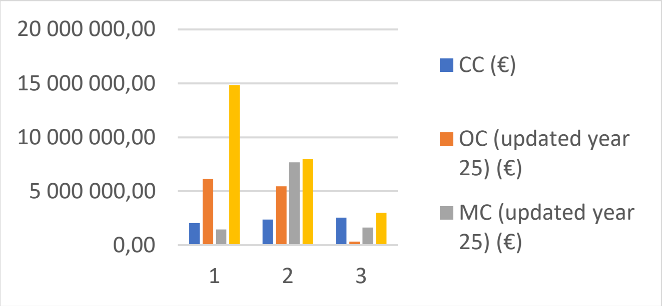

Figure 6. 1 - Comparison of costs between the different options

Out the three options the one that performs best is option 1 because, although the sustainable contribution is the same as that of option 2, its result and attractiveness are higher.

6.2. Sensitivity analysis

The sensitivity analysis to the results obtained previously is carried out on those parameters for which it is not possible to guarantee great rigour and to which the final result is more sensitive.

Therefore, the parameter is varied by a fixed percentage upwards and/or downwards in relation to the estimated value, and the results obtained are compared. The analysis should be done one parameter at a time in order to avoid interacting influences and to better understand the individual effect on the final result.

Therefore, the target parameters of this sensitivity analysis are:

- Discount rate
- Price of purified water (revenue)
- Cost of maintenance

6.2.1. Discount rate

The discount rate, a very important parameter, is the factor that converts future costs into current costs, and its choice can have a significant influence on the investment decision. The value used previously, and constant throughout the analysis of the study options, is 6%.

Therefore, in this sensitivity analysis, this rate varied by ±3%. This variation was decided to be able to test high and low update rates that are within admissible values (Mendes, 2011). The results are presented in Table 6.2.

Table 6. 2 - Discount rate sensitivity analysis

Option	Estimated rate (6%) NPV (€)	Expected rate -3% (3%) NPV (€)	Expected rate +3% (9%) NPV (€)
1	14 861 540,67	25 452 445,72	8 720 498,99
2	7 957 208,62	16 143 784,59	3 351 010,18
3	2 994 890,40	6 427 497,00	1 001 079,50

As expected, the lower discount rate (3%) corresponds to higher NPV values, which is more profitable than the initial analysis.

Considering the 9% discount rate, the NPV values of the options are lower, as it begins to require a higher profitability of the investment options.

Although this variation in the discount rate shows that all options are viable, Option 1 continues to be the option with the best results in economic terms.

6.2.2. Price of purified water (revenue)

Knowing that water is a scarce natural resource and given that only 3% of the planet's water is available for consumption, it is predictable that in the future and in a scenario of water stress, the price of drinking water will increase significantly. Likewise, the price of water to be reused will also increase.

Therefore, it makes sense to analyse the results against a tripling of current prices. At the academic level, we also test the results against a 10-fold increase.

The price of drinking water estimated previously is 1,25 €/m^3 and that of purified water is 0,70 €/m^3. Using the percentage method and tripling the price of drinking water, the predicted value of purified water (for reuse) is 2,10 €/m^3.

Similarly, and using the same method, the predicted value of purified water is 7,00 €/m^3, which is 10 times higher than the "current" price.

The results obtained for each of the options studied are shown in Table 6.3.

Table 6. 3 - Sensitivity analysis on the price of purified water

Option	Estimated (0,70€/m^3) VAL (€)	Expected x3 (2,10€/m^3) VAL (€)	Expected x10 (7,00 €/m^3) VAL (€)
1	14 861 540,67	61 963 885,17	226 822 090,92
2	7 957 208,62	54 854 839,93	218 996 549,48
3	2 994 890,40	18 002 372,40	70 528 559,50

When the price of water to be reused triples or is 10 times higher than today, the NPV values increase significantly, and the break-even points are reached in fewer years than those calculated in setion 5 (baseline scenario).

This shows that, in the near future, both options will be viable, with Option 1 remaining the most viable of all.

6.2.3. Cost of maintenance

Regarding construction costs, these are costs that have a major impact on all costs associated with the analysis of economic viability.

Consequently, a sensitive analysis of this parameter becomes relevant, in order to be able to determine NPV values and verify if there is any influence on the results.

To this end, a variation of ±5% was considered.

Table 6. 4 - Sensitivity analysis of construction costs

Option	Estimated cost VAL (€)	Expected cost (-5%) VAL (€)	Expected cost (+5%) VAL (€)
1	14 861 540,67	14 963 856,60	14 759 224,75
2	7 957 208,62	8 075 407,17	7 839 010,08
3	2 994 890,40	3 122 254,60	2 867 526,30

Comparing the results, it can be seen that the results obtained reveal differences between 1% and 4%. Thus, despite the construction costs being an essential component for all the costs of the solutions, the variation of ±5% does not reflect in significant variations in the NPV. In other words, the variations in NPV are lower than the variation considered for construction costs.

It can be stated that this is because the initial costs may be offset by the operation and maintenance costs, so that it can be considered that this small increase in the initial investment corresponds to a better quality construction (for example, through better equipment).

6.3. Limitations of the work carried out

The possible uncertainties and error factors in the economic feasibility analysis are related to the lack of available and reliable data for the choice of the various parameters of the analysis, not only in terms of costs, but also in terms of performance data of the equipment that constitute the solutions adopted for each option.

Therefore, the process of collecting information becomes complex and time-consuming, since sometimes data is non-existent and has to be collected/aquired from unreliable sources.

In the present study options, the most evident limitations are related to the calculation of maintenance and operation costs. This is because maintenance and operation for this type of facility is a field that has been little studied. This situation would be more evident if the analysis were carried out over longer periods.

That being said, some performance and cost estimates may not be the closest to reality, and the options considered most viable in economic terms may not be so in practice.

Another important aspect to consider is the constant evolution of prices, technology and knowledge, which means that the options considered to be the most advantageous for the local closure of the urban water cycle may not be so in the future.

In addition to the issues mentioned above, the fact of not having included in the analysis the fixed costs of the equipment necessary for the distribution of purified water for landscape irrigation and street washing in the area to intervene, leads this analysis not to be very conservative.

7. Conclusions and Recommendations

7.1. Conclusions

The analysis consisted in estimating a price for purified water, thus closing the urban water cycle, since it is considered that this water will be reused. After estimating this cost, we analysed which of the options created obtained the best economic results and sustainable contribution.

In conclusion, both options are advantageous to implement as they all showed a positive internal rate of return and a very profitable value.

Option 1, with an IRR of 15% and a result of 14 million euros, is the one that presents the best results at the economic and environmental level, in other words, it is the most promising solution for the possible closure of the urban water cycle. This option does not make compatible the fixed costs associated to the reuse of treated water. However, if these costs had been included, the analysis would be more accurate, and possibly increase the initial investment costs of this option, making Option 1 less economically appealing than Option 2.

In Option 2, with an IRR of 7% and a result of almost 8 million euros, despite not presenting such a good profitability as option 1, but taking into account what was mentioned in the previous paragraph, it becomes the most advantageous option to implement, both from an economic and environmental point of view. However, it is important to note that, in this solution, the fixed costs associated with the infrastructures for the reuse of water were not taken into account. But taking that into account, in this solution, wastewater treatment is done close to the neighbourhoods, allowing the purified water to be automatically used for eventual irrigation of green spaces and washing of streets inserted in, or even close to, the neighbourhoods.

Regarding option 3, with an IRR of 6 % and a result of approximately 3 million euros, although it is plausible to implement, it is a solution that needs more data in order to state whether or not it is viable to be implemented, to the extent that in terms of sustainable contribution, this option does not present an advantage.

7.2. Recommendations for possible future work

At the urban scale, it is recommended for similar studies the application of an economic viability analysis of the inclusion of sustainable measures as it allows determining whether the project is advantageous or not.

The recommendations for future developments are related not only to the above mentioned, but also to the consideration of the fixed costs, initial investments, of the distribution solutions. That is, to consider in the analysis the total costs of the irrigation systems for green areas and the equipment for street washing, in order to make the analysis more realistic.

It is recommended that in the future, there is greater transparency in the prices practiced and an updated database that can be consulted for a more accurate and realistic analysis.

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