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WATER CIRCULARITY AND ECO-EFFICIENCY IN CULATRA ISLAND

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Declaration of Work Authorship

I declare that I am the author of this work, which is original and unpublished. Authors and works consulted are duly cited in the text and are included in the list of references included.

María Andrés Torres

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Abstract

Islands are remote areas surrounded by water far away from the continent. They present challenges (e.g., water/wastewater management and energy dependency on the mainland) aggravated by climate change, demographic trends and unsustainable consumption. To fight against these obstacles, islands are developing innovative, environmental-friendly and sustainable solutions, becoming ideal examples for other islands.

Culatra Island is a small island located in the south region of Portugal: the Algarve. To resolve the above-mentioned challenges, Culatra has developed solutions to overcome energy and water dependency on the mainland through the "Culatra2030 - Sustainable Energy Community" initiative, creating measures to adapt to climate change, promote circularity and enhance sustainability. This work will try to ameliorate water management sustainability on the island, improve and optimise its efficient use and its circularity and address different alternative sources of water for non-potable uses. Two reference buildings (the Social Centre and the Primary School) were selected to work with the community towards the efficient use of water treated for human consumption, using an educational approach and installing water flow reducers in the mentioned buildings. Later on, the nexus water treated/energy/carbon emissions were studied to understand the environmental impact. Furthermore, the needed actions to modify the non-potable uses of water utilizing groundwater abstraction, rainwater harvesting, seawater desalination and reuse of water were assessed. Eventually, in a way to answer people's needs, a questionnaire was written in collaboration with the Associação de Moradores da Ilha da Culatra.

Results show that by installing water flow reducers, water efficiency is improved and, therefore, indirectly it is as well the use of energy and its associated carbon emissions. The four alternative water sources studied proved to be great options to modify non-potable usage of water. Finally, Culatra's community participation was essential to understand their position on water sustainability, efficiency and circularity.

Keywords: water sustainability; water flow reducers; alternative sources of water; community engagement.

Resumo

As ilhas são territórios rodeados por água a distâncias variáveis dos continentes. Estes locais apresentam desafios tais como, a gestão da água/águas residuais e a dependência energética do continente), agravados pelas alterações climáticas, tendências demográficas e padrões de consumo insustentáveis. Para enfrentar estes desafios algumas ilhas têm desenvolvido soluções inovadoras, amigas do ambiente e sustentáveis, para que possam servir de exemplo a outras ilhas.

A Ilha da Culatra é uma pequena ilha localizada a sul de Portugal no Algarve. Numa tentativa de responder aos desafios acima mencionados, a Culatra tem vindo a desenvolver soluções para ultrapassar a dependência energética e hídrica do continente, através da iniciativa “Culatra2030 - Comunidade Energética Sustentável” criando medidas de adaptação às alterações climáticas, promovendo a circularidade e potenciando a sustentabilidade. Este estudo pretende melhorar a sustentabilidade da gestão da água na ilha, promover e otimizar o seu uso eficiente e a sua circularidade, avaliando possíveis origens alternativas de água para usos não potáveis. Foram estudados dois edifícios na ilha, o Centro Social e a Escola Primária, trabalhando com a comunidade a importância do uso eficiente da água tratada para consumo humano, numa abordagem educacional e através da instalação de equipamentos de redução de caudal nos mesmos. Depois, estudou-se a relação água tratada/energia/emissões de carbono, para perceber o desempenho ambiental. De seguida, avaliaram-se as ações necessárias para se alterar os usos não potáveis de água. Estudou-se ainda a possibilidade de captação de água subterrânea, água da chuva, dessalinização de água marinha, e reutilização de água. Finalmente, com o intuito de responder às necessidades das pessoas, realizou-se um questionário com a colaboração da Associação de Moradores da Ilha da Culatra.

Os resultados mostraram que a instalação de redutores de caudal melhoram a eficiência hídrica, como consequência melhora os consumos de energia associados e reduz as emissões de carbono. As quatro fontes alternativas de água são excelentes opções de utilização de água não potável. Finalmente, a participação e envolvimento da população foi essencial para compreender a sua posição em relação à sustentabilidade, eficiência e circularidade da água.

Palavras-chave: sustentabilidade da água; redutores de caudal; recursos alternativos de água; envolvimento da comunidade

Resumen

Las islas son áreas remotas rodeadas por agua, alejadas del continente, que presentan dificultades (i.e, gestión de agua/aguas residuales y dependencia energética del continente) agravadas por el cambio climático, tendencias demográficas y consumo insostenible. Para afrontarlas, las islas están desarrollando soluciones innovadoras, amigables con el medio ambiente y sostenibles, convirtiéndose en ejemplos ideales para otras islas.

La Isla de Culatra se encuentra en el sur de Portugal: el Algarve. Para resolver los obstáculos mencionados, Culatra ha desarrollado soluciones para sobrepasar la dependencia energética y acuática a través de la iniciativa "Culatra2030 – Comunidad Energética sostenible", adaptándose al medio ambiente, promoviendo la circularidad y mejorando la sostenibilidad. Este trabajo perfeccionará la gestión sostenible del agua en la isla, promoverá y optimizará su uso eficiente y su circularidad, y evaluará diferentes fuentes alternativas de agua. Dos edificios de referencia (el Centro Social y la Escuela Primaria) fueron escogidos para trabajar con la población hacia el uso eficiente de agua, usando un abordaje educativo e instalando reductores de agua en los edificios. Después, la conexión agua tratada/energía/emisiones de carbono fue estudiada para entender el impacto medioambiental. Más tarde, fueron evaluadas las acciones para modificar los diferentes usos de agua utilizando extracción de agua subterránea, recolecta de lluvia, desalinización y reutilización de agua. Por último, un cuestionario fue escrito en colaboración con la Associação de Moradores de la Isla de Culatra.

Los resultados muestran que la instalación de reductores de agua mejora la eficiencia hídrica y, por lo tanto, indirectamente también es mejorado el uso de energía y las asociadas emisiones de carbono. Las cuatro fuentes alternativas de agua estudiadas son una óptima opción para modificar los usos no potables de agua. Finalmente, la participación de la población fue esencial para entender su posición en relación con la sostenibilidad, eficiencia y circularidad del agua.

Palabras clave: sostenibilidad del agua; reductores de agua; fuentes alternativas de agua; compromiso de la comunidad.

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1. Introduction

1.1. Water as a Natural Resource

Water is an indispensable resource for life (Westall & Brack, 2018; Butts, 1997). Due to its structure (two atoms of hydrogen attached to one atom of oxygen, H_20), the molecule of water has specific properties which make it essential for life. Such properties, among others, are the high heat retention, giving resistance to dehydration; the high dielectric constant and the high density of water, allowing the dissolution of vital salts for life; and its polarity, conferring the ability to make covalent bonds and making water having as polymeric-like structure (Chaplin, 2001; Westall & Brack, 2018). Such is its importance that water is considered a public good fundamental for life and health. The reason why, on the 28th of July 2010, water and sanitation were officially recognised as human rights by the United Nations. The human right to water is vital to realise other human rights and should be meeting other rights, among them, the right to life and human dignity (General Comment n.º 15, 2002; Neto *et al.*, 2020).

Moreover, water is abundant all over the Earth's surface; 70 % of the globe is covered by water. However, only 3 % is freshwater, and from that 3 %, only 0,7 % is used and accessible for human activities. The remaining 1,8 % stays inaccessible in glaciers, polar ice caps and deep aquifers (Butts, 1997; Gude et al., 2011; Gude & Nirmalakhandan, 2010; Kumar et al., 2022; Samuel *et al.*, 2022; Tanck, 2017). Hence, despite being abundant on the Earth's surface, water is scarce and finite for which there is no substitute. This scarcity is unequally distributed throughout the world, being arid and marginal regions the most affected ones (Butts, 1997; General Comment n.º 15, 2002; Gude, 2016; Muscatelli *et al.*, 2020; Sauvé *et al.*, 2021). Owing to this, it is believed that the current international political and social instabilities and violent conflicts are caused by water and its paucity (Butts, 1997; Gude, 2016).

Besides the quantity of water, its quality is also being affected. That is, contamination and degradation of water bodies are becoming very critical. Organic pollutants and microplastics are ending up in aquatic bodies due to anthropogenic activities (e.g., wastewater discharges). These actions, together with climate change pressures, reduce the availability of fresh clean water and deteriorate the ecosystems and their biodiversity, causing, eventually, adverse effects on human health (Cravo *et al.*, 2022; Gude, 2016; Hao Ngo *et al.*, 2020; Hey *et al.*, 2014; Lee *et al.*, 2019; Miklos *et al.*, 2018; Nika *et al.*, 2020; Olasupo & Suah, 2021; Ramírez-Agudelo *et al.*, 2021; Rodrigues *et al.*, 2021; Samuel *et al.*, 2022; Tijani *et al.*, 2014; Vivekanand *et al.*, 2021; Wu *et al.*, 2015; Xiang *et al.*, 2022).

All these concerns will be enhanced by the combined effect of climate change, global demographic trends and improperly water management (Arora *et al.,* 2022; Butts, 1997; Campisano *et al.*, 2017; Gude, 2016; Hao Ngo *et al.*, 2020; Serrao-Neumann *et al.*, 2019; Waite, 2012; Wong *et al.*, 2020; Wu *et al.*, 2015). Therefore, proper solutions are needed.

1.2. Sustainable Management of Water

In 2015 the United Nations adopted the 2030 Agenda for Sustainable Development, in which all member states committed to achieving 17 Sustainable Development Goal (SDGs). Some of those goals aim to achieve sustainability of water: SDG-6 intends to ensure Sustainable Urban Water Management (i.e., improve water quality, increase water use efficiency and restore water-related ecosystems); SDG-11 aims to make cities and human settlements resilient and sustainable; SDG-12 intend to provide tools and knowledge to people to ensure sustainable consumption pattern ; and SDG-14 aims to prevent, conserve and enhance marine and coastal ecosystems by scientific research and transfer the new knowledge acquire, and increase the economic benefits of small islands by sustainable management (Rosa, 2017).

Water in the environment follows a natural circular model. The water precipitates on the Earth's surface as rain and flows over the surface. This water evaporates and eventually return to the Earth's surface by its precipitation, closing this cycle named the water cycle or hydrologic cycle (Arora et al., 2022; Brutsaert, 2005; Gude, 2016; Nika *et al.*, 2020; Sauvé *et al.*, 2021). However, when thinking of water in urban water systems, this resource is managed by human decisions following an anthropogenic water cycle (Arora et al., 2022; Liu et al., 2013). Water is extracted from different primary sources (e.g., surface water, groundwater, and seawater) to meet urban water demands, used, qualitatively degraded, and discharged, eventually, as wastewater into the water cycle. This strategy is no longer sustainable due to its imprudent consumption of resources and contamination of the environment (Arora et al., 2022; Arup *et al.*, 2018; Nika *et al.*, 2020; Ramírez-Agudelo *et al.*, 2021; Sauvé *et al.*, 2021). Sustainable approaches are, therefore, needed to strengthen the environment and protect water (Serrao-Neumann *et al.*, 2019), and water circularity is one of them. This methodology is based on the substitution of primary water demands by the portion of wastewater that is treated to a water qualitys level and can be reused. By doing this, water demands and discharges are saggregated at a city level, absorbing the complexities of sourcing and distribution system across the urban water systems. (Arora et al., 2022). In this path to secure sustainable development, eco-efficiency is also an aspect to consider. This concept measures the efficiency with which resources are used to meet human needs, showing how efficient the economic activity is regarding nature's goods and services. This way, the environmental performance is enhanced by minimising the consumption of resources (Liu et al., 2013), which in this case is water. Moving forward sustainability, the circular economy model plays an essential role in the pursuit of water efficiency and circularity. This paradigm seeks to lower the amount of water used by minimising their linear process and increasing their recirculation and reuse, reducing waste production and improving environmental, social and economic sustainability (Arup *et al.*, 2018; Nika *et al.*, 2020; Ramírez-Agudelo *et al.*, 2021; Sauvé *et al.*, 2021).

By following the above strategies, urban water management transforms into a Sustainable Urban Water Management. Aside from achieving water efficiency and reuse, others such as urban water balance restoration and multifunctional ecosystems can be accomplished (Ramírez-Agudelo *et al.*, 2021). However, its application is, somehow, complex and presents some challenges. Firstly, a change from centralised to decentralised water systems is required to accomplish Sustainable Urban Water Management (Nika *et al.*, 2020; Ramírez-Agudelo *et al.*, 2021; Serrao-Neumann *et al.*, 2019). Centralised water systems imply the use of unique water treatments and are no longer sufficient when treating rather polluted waters; whilst decentralised water systems imply the use of multiple methodologies, allowing not only the recovery and reuse of treated waters (Rashidi *et al.*, 2015; Wu *et al.*, 2015), but also reduce water demands and sewage loads (Wong *et al.*, 2020). Secondly, make the interaction between science and policy less complicated. That is, create and establish strong regulations, policies, and programs coordinated with water planning and circularity. For that, interdisciplinary approaches, good decision-makers, proper communication between them and commitment to collaboration are needed (Arora et al., 2022; European Economic and Social Committee, 2017; Liu et al., 2013; Neto *et al.*, 2020; Nika *et al.*, 2020; Pacheco *et al.*, 2022; Sauvé *et al.*, 2021; Venckute, 2017; Wong *et al.*, 2020). Thirdly, it is crucial to make water management integrated and adaptative, and connect it with different sectors and resources, always from an environmental-friendly perspective. The water sector is strongly linked with the energy one. That is, when supplying or treating water, there is an electricity consumption that releases carbon-related gases. It is crucial to enhance water circularity and eco-efficiency and to seek greener technologies (e.g., the use of biogas from sludge digestion promoting, this way, circular economy) that minimise the impact of those emissions on the environment (Arora *et al.,* 2022; Kumar *et al*., 2022). Moreover, to make water management adaptative and connect it with other sectors, data and information sharing are essential. This might be one of the most challenging aspects to carry out due to the accessibility of data, ownership, trust, security and privacy between the involved parties (Arora et al., 2022; Nika *et al*., 2020; Sauvé *et al*., 2021; Wong *et al*., 2020). Fourthly, water consumption habits and the behaviour of users should change to achieve circular economy (Neto *et al*., 2020; Serrao-Neumann *et al*., 2019; Venckute, 2017). Education, here, plays an important role. Together with technological innovation and infrastructural investment, both sustainable development and efficient use of water can be accomplished (Arora *et al*., 2022; Gude, 2016; Liu *et al*., 2013; Neto *et al*., 2020; Venckute, 2017). Along with education, the term water footprint should be understood, considered and improved to move towards sustainability. It represents the consumption and freshwater pollution caused by human activities, not only domestic ones but also industrial ones. It is an indicator that includes both the direct and indirect use of this resource (Neto *et al*., 2020; Sauvé *et al*., 2021). Therefore, it is up to people's involvement, together with technology, if they want to shift to this paradigm and reorganise their consumption habits to avoid problematic environmental situations (Neto *et al*., 2020).

1.3. Water Sensitive Communities

Urban areas are increasing in terms of numbers and population, making cities critical to achieving sustainable development of resources (i.e., water) in them (Wong *et al*., 2020). Water sensitive communities, where nature based solutions are applied (i.e., ecological landscapes based on preserving or mimicking natural processes to support and overcome urban challenges such as environmental quality, climate change and socio-economic issues, among others (Jeuken, 2020; Wong *et al*., 2020)), are a cure to unsustainability. These areas are examples where circular economy is applied, and sustainability of water is achieved. The concept of water sensitive communities represents the connection between institutions and infrastructures, ensuring sustainable water resource management. It represents the climax of water supply, sanitation and environmental protection, bringing not only the sustainability of water but also resilience, prosperity and some ecosystem services (benefits provided by nature) such as improved environmental and human health, urban amenity, recreational opportunities, and decrease of the Heat Island Effect. This sustainable measure can also improve water efficiency. For that, it is crucial to diversify water sources (e.g., harvest and use rainwater and stormwater, recycle wastewater, and use groundwater) and suit its utilisation for different fit-for-purpose uses (e.g., outdoor usage, agriculture) (Serrao-Neumann *et al.*, 2019; Wong *et al.*, 2020).

This innovative strategy can be summarised as best management practices (BMPs), low impact development (LID), sustainable drainage systems (SuDS), and water sensitive urban design (WSUD) (Xu *et al.*, 2019). They are found all over the world. Cities in Europe (Figure 1.1) such as Copenhagen (Denmark), Utrecht (The Netherlands) and Zurich (Switzerland) (Jeuken, 2020) are pioneers in being water sensitive communities. Furthermore, it is worth mentioning that Australia is the leader in implementing WSUD strategies, especially in the region of Greater Adelaide (Gude, 2016; Wong *et al.*, 2020); China is well known for its Sponge Cities; Singapore for designing its Active, Beautiful and Clean (ABC) waters, and the United States for implementing LID measures (Wong *et al.*, 2020). Although it is well implemented, once again, some barriers and limitations need to be overcome. These are, once more, social and institutional challenges. In the social area, people still feel distrusted regarding the reuse of recycled water, a feeling which is strengthened by the lack of supportive initiatives, research and information (Arora et al., 2022; Serrao-Neumann *et al.*, 2019; Wong *et al.*, 2020). In the institutional area, the traditional approach is so deeply rooted in society that moving to the new approach, where decentralised systems and nature-based solutions are combined with the already implemented systems, creating hybrid systems, is time- and money-consuming. Moreover, the current governance and normative, as above-mentioned, do not support technological innovation and research, complicating the needed transition from the linear economy model to the circular economy one (Serrao-Neumann *et al.*, 2019; Wong *et al.*, 2020). Additionally, the biophysical conditions also play an important role when implementing these strategies, such as the city's hydrology, geomorphology and microclimate (Wong *et al.*, 2020).

Figure 1.1 European water sensitive communities. A) Copenhagen (Denmark). B) Utrecht (The Netherlands). C) Zurich (Switzerland). (Source: Jeuken, 2020).

1.4. Sustainable Islands

Around the world, it is estimated to find 85.000 islands. Of those, almost 13.000 are inhabited. A total of 750 million people live in these idyllic and diverse places. Despite being idyllic and diverse places to live, they are remote areas surrounded by water far away from the continent. Due to their location, these areas present some challenges and difficulties that will be aggravated by the adverse impact of climate change. Some challenges and difficulties are the water supply, the wastewater management, or the energy dependency on the mainland that need to be overcome. To fight against these obstacles, islands are developing and testing innovative and greener solutions (European Economic and Social Committee, 2017; Hydrousa, 2022; Kaldellis, 2020; Pacheco *et al.*, 2022; Skjølsvold *et al.*, 2020). Thus, islands become ideal test vehicles to develop and conduct pilot projects that will be scaled up to work on the mainland or serve as an example for other island communities (European Economic and Social Committee, 2017; Kaldellis, 2020; Pacheco et al., 2022; Skjølsvold *et al.*, 2020). Hence, islands gain importance for being areas where technological experiments can be carried out and for spread out those technological advances beyond the islands (Skjølsvold *et al.*, 2020). By doing this, islands become prosperous, self-sufficient and sustainable (European Economic and Social Committee, 2017; Kaldellis, 2020). However, it is worth mentioning that the success of these new technologies on the island does not ensure the same success in the mainland or other island communities. Its translation is not always possible due to difficulties that might appear in those other places. In any case, hard work, adaptation, and creativity are key factors (European Economic and Social Committee, 2017; Skjølsvold *et al.*, 2020).

Most of the cases found where islands became sustainable (European Economic and Social Committee, 2017; Kaldellis, 2020; Pacheco *et al.*, 2022; Skjølsvold *et al.*, 2020) analyse and enhance the energy field. Nevertheless, there are few other examples (Table 1.1) where technological innovations in the fields of wastewater and water management, information and communication technologies, transport, tourism, commerce, and marine conservation are areas to study (European Economic and Social Committee, 2017). Due to the lack of research done in these last sectors, this work will be innovative in the field of wastewater and water management. All the knowledge and experience gained in other projects and other fields will be transferred to the water one.

Table 1.1 Examples of islands where water management, tourism and commerce solutions have been implemented (Source: European Economic and Social Committee, 2017).

Island	Country	Technology	Research field
Favignana	Italy	To reduce plastic waste, an outdoor fountain was installed to distribute water to the Favignana islanders. Since 2014, roughly 150.000 plastic bottles have been saved.	Water management
Island of Yeu	France	Development of sustainable tourism through the creation of a long coastal footpath around the island and routes for hiking, always preserving the natural areas and the architectural heritage.	Tourism
Saaremaa	Estonia	Label island's products to encourage small producers of beverages and make local production more attractive and visible.	Commerce

Furthermore, as it has been seeing throughout this work, to fully implement these solutions, a modification in policies and regulations is needed. The case of sustainable islands is not an exception. It is fundamental to elaborate policies and recommendations for enabling the transition of "normal" islands to sustainable islands where technological advancements and innovation in research are taken into consideration (Kaldellis, 2020). Moreover, not only proper legislation is a key factor for the correct development of sustainable islands. Good management from the people in charge (Skjølsvold *et al.*, 2020), together with social innovation and participation of islanders in the project, is crucial to understanding the needs of the island and for the achievement of sustainable islands (European Economic and Social Committee, 2017; Pacheco *et al.*, 2022). Local authorities should interact, communicate, inform and involve residents when designing and implementing the project. Furthermore, interdisciplinary consortiums have proven to increase the effectiveness and be crucial for a better implementation of new technologies on islands. The exchange of knowledge and learning from the experts' experience guide islands towards the highest success (European Economic and Social Committee, 2017; Pacheco *et al.*, 2022).

1.5. Initiative Culatra2030

Culatra Island (Figure 1.2) is a small island located in the south region of Portugal: the Algarve. It is about 7 km in length and 1,2 km wide, constituting an island with a total area of 4,34 km^2 that is inhabited by roughly 1.000 people. It is located in the barrier islands that compose the Ria Formosa Natural Park (Culatra 2030, 2022; Pacheco et al., 2022). The Ria Formosa is a shallow coastal lagoon system that measures 55 kmslong and 6 km wide, with a total area of 100 km^2. The lagoon connects to the Atlantic Ocean through six inlets allowing the recirculation of water within the system and a permanent exchange with the ocean (Cravo et al., 2022; Rodrigues et al., 2021). This area is one of the most studied and significant ecosystems on the south coast of Portugal due to its biodiversity, ecology, economy and unique social values. Regarding the economy, the source of income is related to mollusc farming and fishing, or even salt production. This fact is expected considering that the Ria Formosa represents the most productive aquaculture zone in Portugal, representing 41 % of the national production according to Pacheco *et al.* (2022) but 80 % according to Rodrigues *et al.* (2021). Concerning social values, tourism becomes assignificant economic income, especially in summer, when the population on the island triples (Cravo *et al*., 2022; Pacheco *et al.,* 2022; Rodrigues *et al*., 2021).

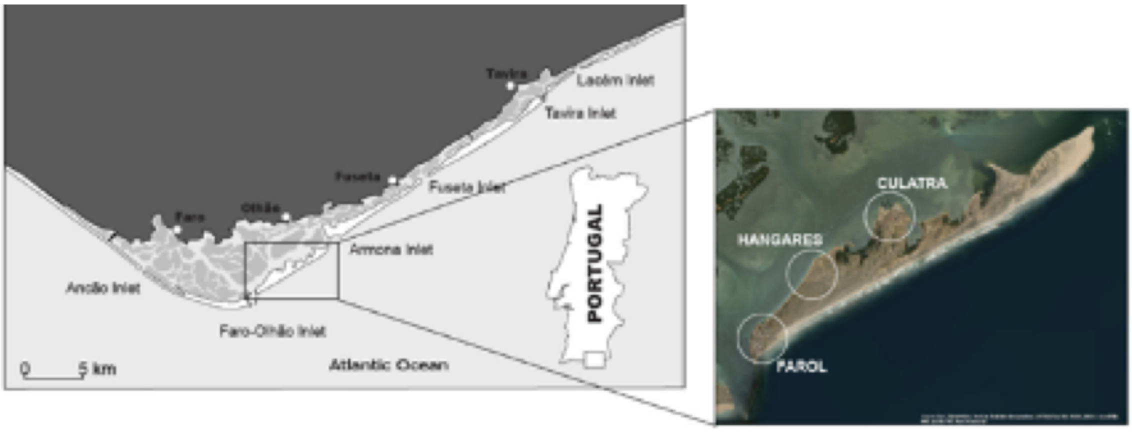


Figure 1.2 Situation of Culatra Island (36.9937-N; 7.839793-W) in the Atlantic Ocean (Source: Pacheco et al., 2022)

Just like other islands, Culatra Island also faces, as above-mentioned, challenges like wastewater management, water supply, seasonal fluctuation of tourists, and energy scarcity and dependency on the mainland, all of them aggravated by climate change (Kaldellis, 2020; Pacheco *et al*., 2022; Skjølsvold *et al*., 2020). At the moment, the energy insufficiency and dependency are being resolved through the "Culatra2030 - Sustainable Energy Community" initiative, where the transition to greener technologies (e.g., implementation of solar photovoltaic (Pacheco *et al.*, 2022) is being accomplished. The objective of this measure is to adapt Culatra to climate change, promote circular economy and enhance environmental sustainability (Culatra 2030, 2022). The great success of this initiative is due to the involvement of residents and institutions collaborating and supporting the project. The communication between the implicated people and their full participation allows the selection of the best solutions to be implemented, increasing the final benefits (Pacheco *et al.*, 2022). The next step is the transition in water management, transforming Culatra into a sustainable island. For that, the same way as it has been doing for the energy field, a complete contribution from islanders, stakeholders and experts in the area will be essential (European Economic and Social Committee, 2017; Pacheco *et al.*, 2022; Skjølsvold *et al.*, 2020), to guide Culatra towards that goal. Moreover, there will also be a transition in water supply and water treatment. In any case, when choosing a specific technology to achieve this water transition, there are environmental constraints owing to the location of the island inside the natural protected area of Ria Formosa (Pacheco *et al.*, 2022; Resolução do Conselho de Ministros 78/2009) that should be taken into account.

1.5.1. Water Transition in Culatra Island

a) Transition in Water Management

Water management in urban water systems is controlled by human decisions following an anthropogenic water cycle (Arora *et al.*, 2022; Liu *et al.*, 2013) instead of the natural circular model that water follows in the environment (Arora *et al.*, 2022; Brutsaert, 2005; Nika *et al.*, 2020; Sauvé *et al.*, 2021). This human management is no longer sustainable due to its imprudent consumption of water and contamination of the aquatic ecosystems (Arora *et al.*, 2022; Arup *et al.*, 2018; Nika *et al.*, 2020; Ramírez-Agudelo *et al.*, 2021; Sauvé *et al.*, 2021). Eco-efficiency (which measures the efficiency with which resources are used to meet human needs, showing how efficient the economic activity is regarding nature's goods and services (Liu *et al.*, 2013)) appears as an option to follow to secure sustainable development and management of water, not only in urban areas but also on islands. This way, the environmental performance is enhanced by minimising the consumption of resources (Liu *et al.*, 2013). By following this paradigm (i.e., the eco-efficiency option), water management can be transformed into a Sustainable Urban Water Management, where, besides achieving water efficiency, others such as urban water balance restoration and multifunctional ecosystems can be accomplished (Ramírez-Agudelo *et al.*, 2021). Culatra will become, this way, prosperous, self-sufficient and sustainable.

b) Transition in Water Supply

Water is an indispensable resource (Westall & Brack, 2018; Butts, 1997) for which there is no substitute (Butts, 1997; General Comment n.º 15, 2002; Gude, 2016; Muscatelli *et al.*, 2020; Sauvé *et al.*, 2021). Not only because of its paucity and its deterioration, but also to meet the human right to water and sanitation (General Comment n.º 15, 2002; Neto *et al.*, 2020) and satisfy people's needs, it is an urgent to look for different resources of water (below mentioned).

Groundwater Abstraction

Groundwater is the water below the land surface, in the saturated zone, and in direct contact with the ground (Brutsaert, 2005; Decreto-Lei 152/2017). In Portugal, and therefore Culatra Island, groundwater can be used for human consumption when there is no drinking water available (supplied by the municipality) and irrigation, as long as the quality parameters stipulated in the Decreto-Lei 236/98 are achieved. Specifically, groundwater in Culatra is used for irrigation and human-related activities such as cleaning patios. Thus, wells act as private suppliers for some islanders provided that those wells are registered by the Agencia Portuguesa do Ambiente (APA). Nonetheless, special attention should be taken to saline intrusion which can be a problem for some water uses. This phenomenon occurs because the consumption rate is higher than the replenishment rate, making groundwater saltier than it should be (Gude *et al.*, 2011) or because of climate change (e.g., increase in the sea-levels and low precipitation (Waite, 2012)).

Rainwater Harvesting

Rainwater harvesting is considered the most ancient practice to overcome water supply needs. It consists of collecting, storing and treating rainwater from different impervious surfaces placed in cities (e.g., terraces, rooftops, parking lots and sidewalks) (Campisano *et al.*, 2017).

Due to water demand pressures, the use of rainwater has increased in the past years. Its usage covers urban (e.g., toilet flushing, washing streets, laundry), industrial (e.g., powering the heating and cooling systems) and irrigation purposes (e.g., irrigation of public and private gardens, vegetable gardens, recreational and sporting activities) (Campisano *et al.*, 2017; Decreto-Lei 119/2019; Especificação Técnica ANQIP 0701, 2009), and it brings many social, economic and environmental benefits (Table 1.2). Nevertheless, the complete implementation of rainwater harvesting systems in society is not yet achieved due to some disadvantages. Mainly due to economic (e.g., expensive implementation and maintenance costs), social (health risk, poor water quality) and legal constraints (lack of norms that regulate water quality and financial incentives, grants or subsidies) (Campisano *et al.*, 2017).

Table 1.2 Social, economic and environmental benefits that a rainwater havesting system offers. (Source: Campisano *et al*., 2017; HYDROUSA, 2022; Gude, 2016; Waite, 2012).

	Benefits
Social	Brings water self-sufficiency. Increase the agricultural efficiency in urban and rural (food gardens) areas. Community engagement.
Economic	Savings in water and energy consumption
Environmental	Mitigates extreme weather conditions such as intense floods, droughts, and changes in rainfall patterns. Decreases the Island Heat Effect by making the climate more humid. Diminishes runoff. Allows groundwater recharge. Reductions in carbon emissions (i.e., energy consumption) due to the use of less drinking water. Conservation of water resources. Promotes circular economy by reusing local materials for the construction of the rainwater havesting systems.

Seawater Desalination

Although water is one of the most abundant resources on Earth (the Earth is covered 70 % by water), only 3 % is freshwater, suitable for humans and its associated activities (e.g., agriculture and industry) (Butts, 1997; Gude *et al*., 2011; Gude & Nirmalakhandan, 2010; Kumar *et al*., 2022; Samuel *et al.*, 2022; Tanck, 2017). Therefore, considering the amount of water in the oceans, scientists and engineers contemplate desalination as an alternative water supply resource (Gude, 2016), since seawater can serve as an unlimited source (Gude *et al.*, 2011; Gude & Nirmalakhandan, 2010).

Desalination is the process of removing salts from the sea or brackish waters. Two streams are obtained: a freshwater stream with minimal mineral content and a concentrated brine stream. Initially, this methodology was not widely embraced because of technological limits, energy intensity, fossil fuel dependency, high capital costs, social rejection (Gude, 2016; Gude *et al.*, 2011; Gude & Nirmalakhandan, 2010; Kumar et al., 2022; Samuel *et al.*, 2022), and wastes and chemical generated. Special attention should be given to the energy intensity. Energy, water and desalination are linked (Arora *et al.,* 2022; Kumar *et al.*, 2022). Energy is required to obtain clean water through the desalination process. Currently, this energy is provided by non-renewable fossil fuels, resulting in the degradation of the environment and in the release of greenhouse gas emissions that contribute to global warming, accelerating climate change (Gude, 2016; Gude *et al.*, 2011; Gude & Nirmalakhandan, 2010; Wang *et al.*, 2020). Its use is neither a sustainable nor an affordable strategy for meeting future water needs, especially for rural and remote communities, as Culatra Island is, where the grid power or fossil fuels to generate energy may not be ready. In an effort to overcome all these issues, renewable energies (e.g., solar, wind, geothermal and tidal energies) appear like a great option to achieve sustainable desalination (Gude, 2016; Gude *et al.*, 2011; Gude & Nirmalakhandan, 2010; Kumar et al., 2022; Wang et al., 2020). Although the functioning of the desalination technology with renewable energies requires a higher level of expertise and skills from the operators (Gude, 2016), by following this sustainable path, not only the environment will be enhanced, but also the success of desalination. Moreover, it is essential to educate and inform the population about sustainable behaviour to embrace desalination (Gude, 2016) and avoid inappropriate use of the facilities (Delyannis & Belessiotis, 1995).

Solar energy is considered a sustainable process that does not contribute directly to any greenhouse gas emissions and has the advantage that can be stored in batteries or collectors via solar photovoltaics being possible to obtain water during non-sunlight hours (Delyannis & Belessiotis, 1995; Gude, 2016; Gude *et al.,* 2011; Samuel *et al.*, 2022). This kind of energy is considered an affordable solution (Kumar *et al.,* 2022) to desalinate seawater, although Gude & Nirmalakhandan (2010) differ from Kumar *et al.* (2022) in the affordability, which would depend on the materials and machinery used. Improvements and research on technology in the use of solar energy for water desalination will lower the costs, aside from increasing water recovery and enhancing energy efficiency (Gude, 2016; Kumar et al., 2022).

The desalination process carried out by solar energy is called solar distillation, a kind of thermal desalination, where convectional solar stills are used (Figure 1.3) (Gude, 2016; Kumar et al., 2022). The purification process is based on the evaporation and condensation principles and goes as follows. The energy of the sun goes through a transparent surface. The sunlight raises the temperature of a basin underneath the transparent surface, evaporating the water. The water vapour rises to a colder region (i.e., the transparent surface) and condenses, leaving the minerals in the basin. Finally, the water condensate formed on the cooler transparent surface rolls down the surface under the effect of gravity, along with adhesive and cohesive forces. Then, the distillation channel collects and accumulates the drops (Kumar et al., 2022; Samuel *et al*., 2022), resulting, this way, in the desalination of seawater and obtaining “freshwater”.

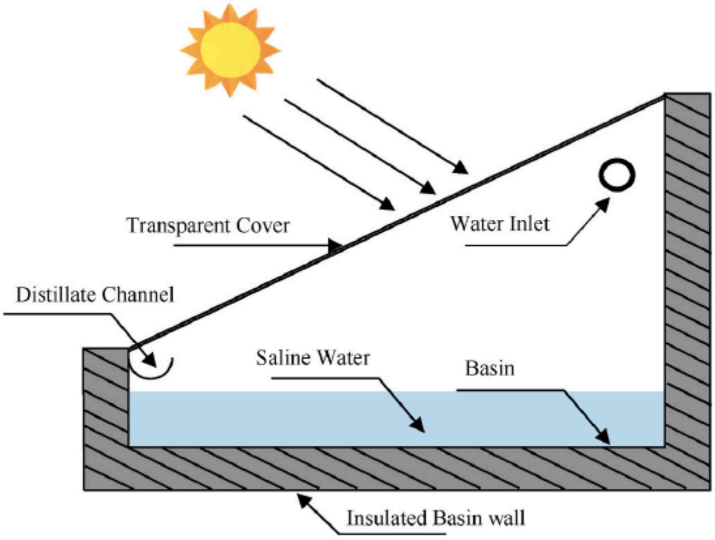


Figure 1.3 Thermal desalination carried out by a convectional solar still. (Source: Kumar et al., 2022).

Desalination is a technique that has been applied on many islands. Since these places are surrounded by seawater, desalination is an easy and viable option to remove the salt and mineral content from seawater and obtain freshwater (Samuel *et al*., 2022). Greek islands like Kimolos (Delyannis & Belessiotis, 1995), Lesvos, Mykonos and Tinos (Hydrousa, 2022), Australia (Gude, 2016) and Taiwan (Samuel *et al*., 2022) are examples of islands where one or another kind of desalination has been used to obtain freshwater. And Culatra Island will be included in this group.

The Algarve region is characterised by a temperate Mediterranean climate with mild and short winters and long, hot and dry summers. The mean temperature throughout the year (Figure 1.4) is around 13,9 ºC (Portal do Clima, 2022), and the global horizontal irradiation is 1.200 W/m^2 (Global Solar Atlas*,* 2022). Due to these climate conditions and the level of solar irradiation, more intense in summer when the water shortage is higher, a solar still will be implemented in Culatra to desalinate seawater, taking advantage of that solar energy. Solar stills are recommended to use in islands owing to their low capital cost, simple construction, easy operation and maintenance (Delyannis & Belessiotis, 1995; Samuel *et al.*, 2022) and, as above-cited, sustainability, since solar stills use solar energy, renewable energy that does not contribute to greenhouse gas emissions (Delyannis & Belessiotis, 1995; Gude, 2016; Gude et al., 2011; Samuel *et al.*, 2022), to desalinate seawater. Moreover, this equipment can be built using locally available materials (Delyannis & Belessiotis, 1995; Kumar et al., 2022; Samuel *et al.*, 2022), contributing, this way, to circular economy and reducing the waste production. The main disadvantage of using this technology is that solar stills are strongly dependent on meteorological conditions, and their low productivity impedes their commercial use (Delyannis & Belessiotis, 1995; Samuel *et al.*, 2022). Nevertheless, its excellent advantages make these systems a promising option for Culatra.

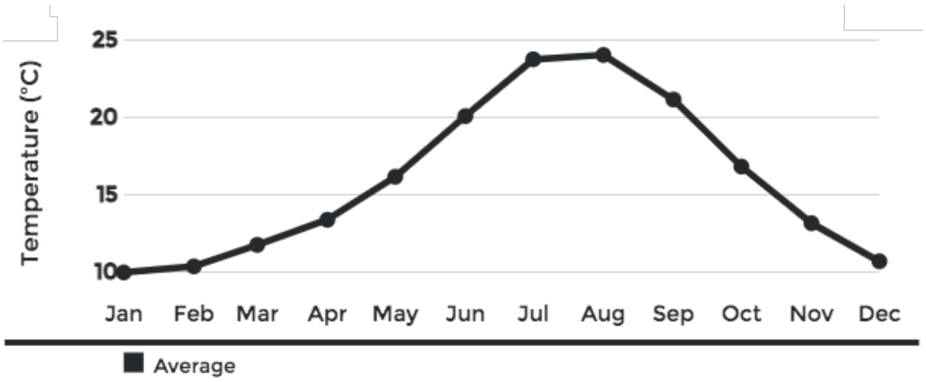


Figure 1.4 Mean temperature in the Algarve region from the year 1971 until the year 2000 (Source: Portal do Clima, 2022)

Water Reuse

The freshwater demand cannot be sustainable only by harvesting rainwater (Wang *et al.*, 2020), desalinating seawater, or using groundwater. Other alternative resources of water need to be found to achieve sustainability.

Water reuse is emerging as a promising non-conventional water resource, although still needs to be given a higher priority and interest considering the water-related issues (Gude, 2016) nowadays happening. Despite water recycling being a potential option to reduce the demand for freshwater, there is, in some scenarios, opposition from the public. In these cases, educational and consciousness-raising campaigns and workshops are a measure to inform people about this new alternative water source. Other new and alternative resources of water not always are suitable for all situations. Hence, water reuse should be considered not only because reduces the demand for freshwater (Gude, 2016) but also because it brings different environmental, social and economic benefits (Decreto-Lei 119/2019; Gude, 2016).

Moreover, water reuse is linked with the reuse of treated wastewater. In Portugal, the attention to reusing wastewater for irrigation and urban activities has grown in the past years due to water scarcity and the increasing interest in finding alternative resources. Hence, the utilisation of wastewater has become a new and alternative source of water in Portugal that allows the preservation of the aquatic ecosystems and water and its future usage. Notwithstanding, in Portugal, wastewater can only be used for irrigation, urban and industrial usage, and scenic uses (Decreto-Lei 119/2019).

1.6. Objective

The general purpose of this work is to promote water circularity and eco-efficiency on Culatra Island. Various measures based on the circular economy model will be implemented to achieve this objective.

Moreover, several specific objectives are intended to be achieved in this work:

1. To characterise the water consumption from Culatra Island. Particularly, two reference buildings will be studied, the Social Centre and the Primary School;
2. To improve the efficiency of water uses in the studied buildings through the implementation of water flow reducers;
3. To analyse the nexus water/energy consumption, in terms of carbon emissions, before the implementation of water flow reducers;
4. To search and characterise different water resources: groundwater, rainwater harvesting, desalination and water reuse;

5. To promote and disseminate improvement measures regarding water circularity and water efficiency in Culatra Island through community engagement, especially among young people.

2. Methodology

Several activities (i.e., field and lab activities) were carried out to collect data and define the correct measures to transform Culatra into a sustainable island, improving its water circularity and efficiency.

2.1. Characterisation of the Water Consumption in Culatra Island

In 2018, 67.557,579 m^3 of water were supplied in Portugal (Águas do Algarve, 2022). That corresponds a total of 185,099 m^3/day of water. From that total amount, around 30% accounts to water losses such leakages in pipes (i.e., 55.000 m^3).

To be more precise and representative of the water usage in Culatra, water consumption was studied and characterised in two different buildings: the Social Centre (Figure 2.1 A)) and the Primary School (Figure 2.1 B)). As shown in Table 2.1, the Social Centre offers support to children between 1 and 10 years old and counted on, during the year 2022, 28 children plus 16 adult workers, whereas the Primary School receives children between 6 and 10 years old and counted on, during the same year, 16 children plus 4 adult workers. Moreover, to evaluate the efficiency of water usage in those buildings, an inspection of the water equipment functioning (flushing, taps and showers) was done. The water flow rate from all the equipment was also measured, as illustrated in Figure 2.2.

Figure 2.1 Studied buildings where water efficiency has been improved. A) Social Centre of Culatra Island (36.990800 N, -7.841100 W). B) Primary School of Culatra Island (36.992056 N, -7.840611 W).

Table 2.1 Social Centre and Primary School characterization during the year 2022.

Public building	Characteristics
Social Centre	Operating hours: weekdays from 9:00 to 18:00; Number of teachers/public workers: roughly 16 adults (once per week the Social Centre receives 11 senior people); Number of students: 28 children; Students' age**:** 1 - 10 years-old.
Primary School	Operating hours: weekdays from 7:45 to 17:30; Number of teachers/public workers: 4 adults (2 teachers and 2 public workers) Number of students: 16 children; Students' age**:** 6 - 10 years-old.

Figure 2.2 Water flow rate measurement *in situ*. (Source: Muller, 2019).

2.2. Water Efficiency Improvements in the Studied Buildings in Culatra Island

Water efficiency in Culatra Island was ameliorated by implementing water flow reducers in some of the equipment (see Table 3.1 in section 3.2.) in the public buildings studied in this work (i.e., the Social Centre and the Primary School). Water flow reducers are complementary devices used in cisterns, taps and showers. In the case of taps and showers, to meet the daily needs of teachers and students, the original filter/diffuser was replaced by the new filters/diffusers with the flow reducer incorporated (Figure 2.3 A) and Figure 2.3 B)). Regarding the toilet flushing, a vinyl bag with a capacity of 2 L was added to them. This way, users now save 2L of water per flush (Figure 2.3 C)).

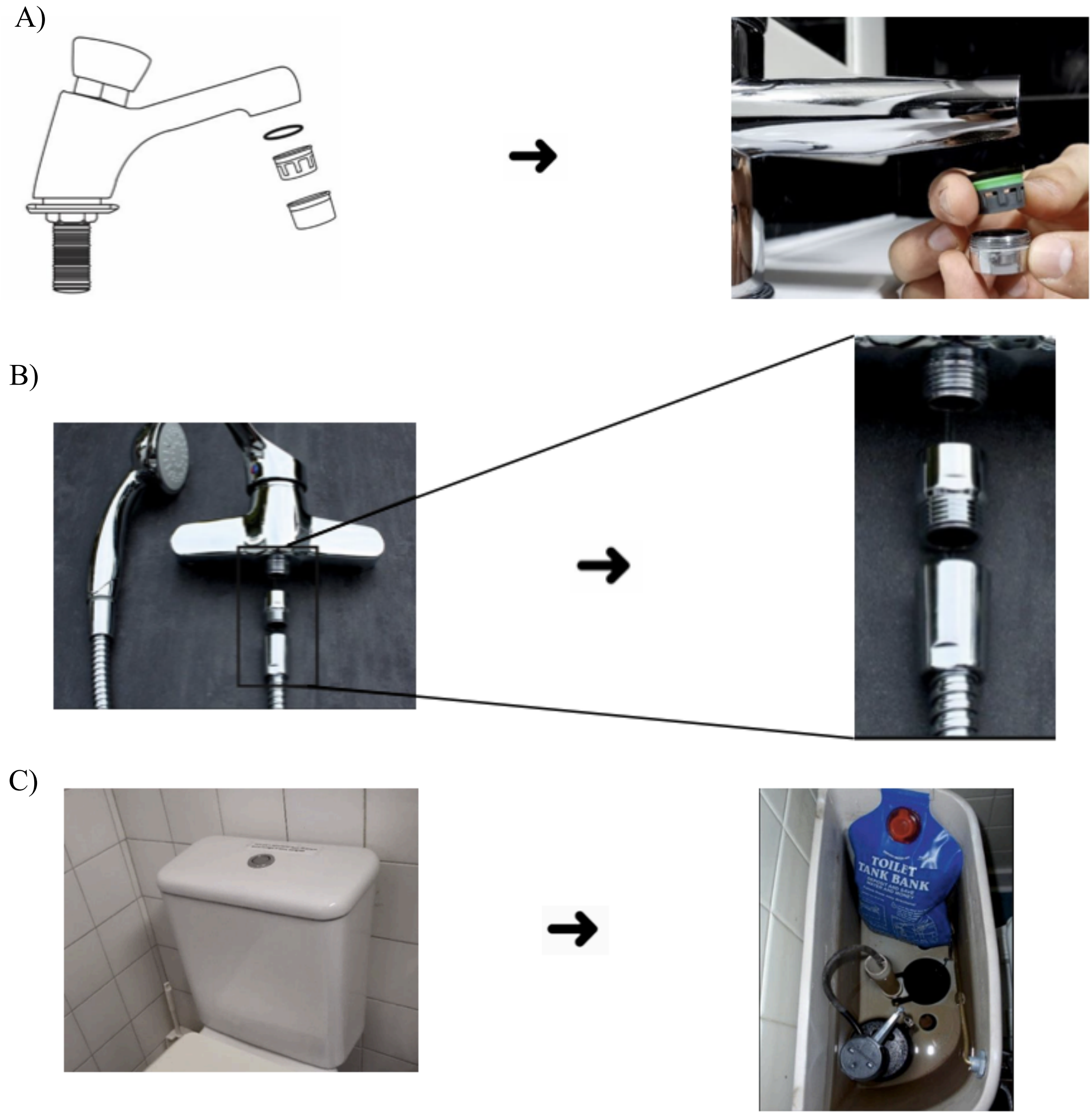


Figure 2.3 Installation of the different water flow reducers in the different equipment. Specifically, A) corresponds to a tap water flow reducer, B) to a shower flow reducer, and C) to a vinyl bag to reduce the water flush in the toilet. (Source: Muller, 2019).

By using these devices, the water flow is directly reduced while maintaining comfort for the teachers and students. Moreover, not only does the amount of water used diminish, but the energy consumption, financial costs, wastewater and the water abstraction from natural resources will also decrease indirectly, contributing to the preservation of the environment.

2.3. Evaluation of the Nexus between Water and Energy Consumption

Energy and water are linked (Arora *et al.,* 2022; Kumar *et al*., 2022). Energy is required to obtain clean water and pump it from the treatment plant to the places where it will be used. Since the energy currently used is provided by non-renewable fossil fuels, the use of such sources results in the release of carbon emissions that contribute to global warming, acceleration of climate change and degradation of the environment (Gude, 2016; Gude *et al*., 2011; Gude & Nirmalakhandan, 2010; Wang *et al*., 2020).

To evaluate the impact of using water, this work will study the energy required for water abstraction and sanitation purposes on Culatra Island, and its associated carbon emissions. Different calculations were done to make such analysis:

- To calculate the energy consumption in the Social Centre and the Primary School, the official data for Portugal from ERSAR (2022) was used. On the one hand, to abstract, produce and transport drinking water to the customer's tap, 1,12 kWh/m^3 are needed. On the other hand, to drainage and treat wastewater 0,46 kWh/m^3 are consumed. The corresponding m^3 of each kind of water can be obtained from the specific water bills from each public building. Thus, by multiplying m^3 of water with its corresponding energy value, the total energy consumption is obtained.

- To calculate the carbon emissions associated to the energy consumption previously calculated, different emission factors were used depending the year. According to the Direção Geral de Energia e Geologia (2022), in 2017, 298 g of CO_2e/kWh were emitted; in 2018, 247 g of CO_2e/kWh; in 2019, 279 g of CO_2e/kWh; and in 2020, 200 g of CO_2e/kWh. These values will be multiplied by the energy consumptions, obtaining this way the carbon emissions associated to that consumption.

2.4. Possible Alternative Water Sources in Culatra Island

Attending to the critical water related issues (e.g., scarcity and contamination of water, and climate change, among others) happening in Culatra Island, distinct and alternative water resources were studied. That is groundwater extraction, rainwater harvesting, seawater desalination and reuse of water from the Social Centre's kitchen.

2.4.1. Groundwater Abstraction

To evaluate the sustainability use of groundwater in Culatra Island, water samples from ten different wells (Figure 2.4) were collected and stored at low temperature in plastic vessels of 25 mL, and finally transported to the Laboratory of Sanitary Engineering for a later salt and conductivity analysis. Salinity was studied using a portable refractometer (ZUZI brand, model FG 211 ATC). Conductivity was quantified by electrometry (Baird *et al.,* 2017) using a conductivity meter WTW Brand, respectively.

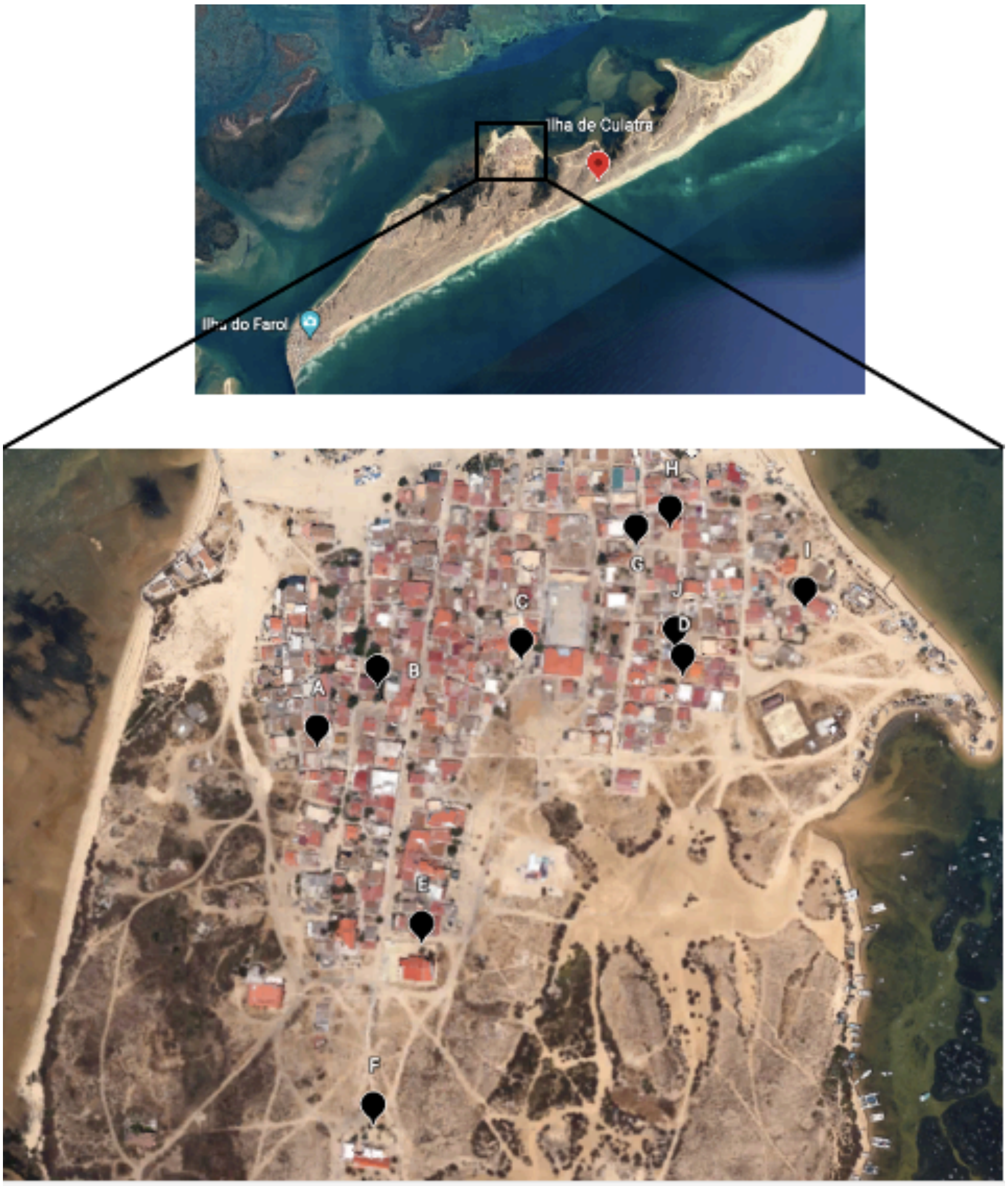


Figure 2.4 Well points where water sample were taken in Cualtra Island. Specifically, A is located 36.993396 N, -7.841435 W; B is 36.993722 N, -7.840944W; C is 36.993972 N, -7.839833 W; D is 36.993889 N, -7.838556 W; E is 36.992056 N, -7.840611 W; F is 36.990972 N, -7.841028 W; G is 36.994694 N, -7.838944 W; H is 36.994722 N, -7.838667 W; I is 36.994278 N, -7.837556 W; and J is 36.9940055 N, -7.8385920 W.

Water salinity and conductivity was compared in different tide conditions. Low tide samples, specifically A to D samples, were taken on the 30th of November 2021, around 11:30 am and 12:00 pm. The remaining ones (samples E to J) were collected on the 6th of December 2021 around 11:30 am and 12:30 pm. According to Figure 2.5 A), samples A to D were picked up when the tide had 2,5 m in height, whereas samples E to J were picked up when the tide had 0,5 m in height (Figure 2.5 B)). The sampling was repeated on the 28th of March 2022, in high ride conditions (almost 3 m) around 12:00 pm and 1:00 pm. Figure 2.5 C).

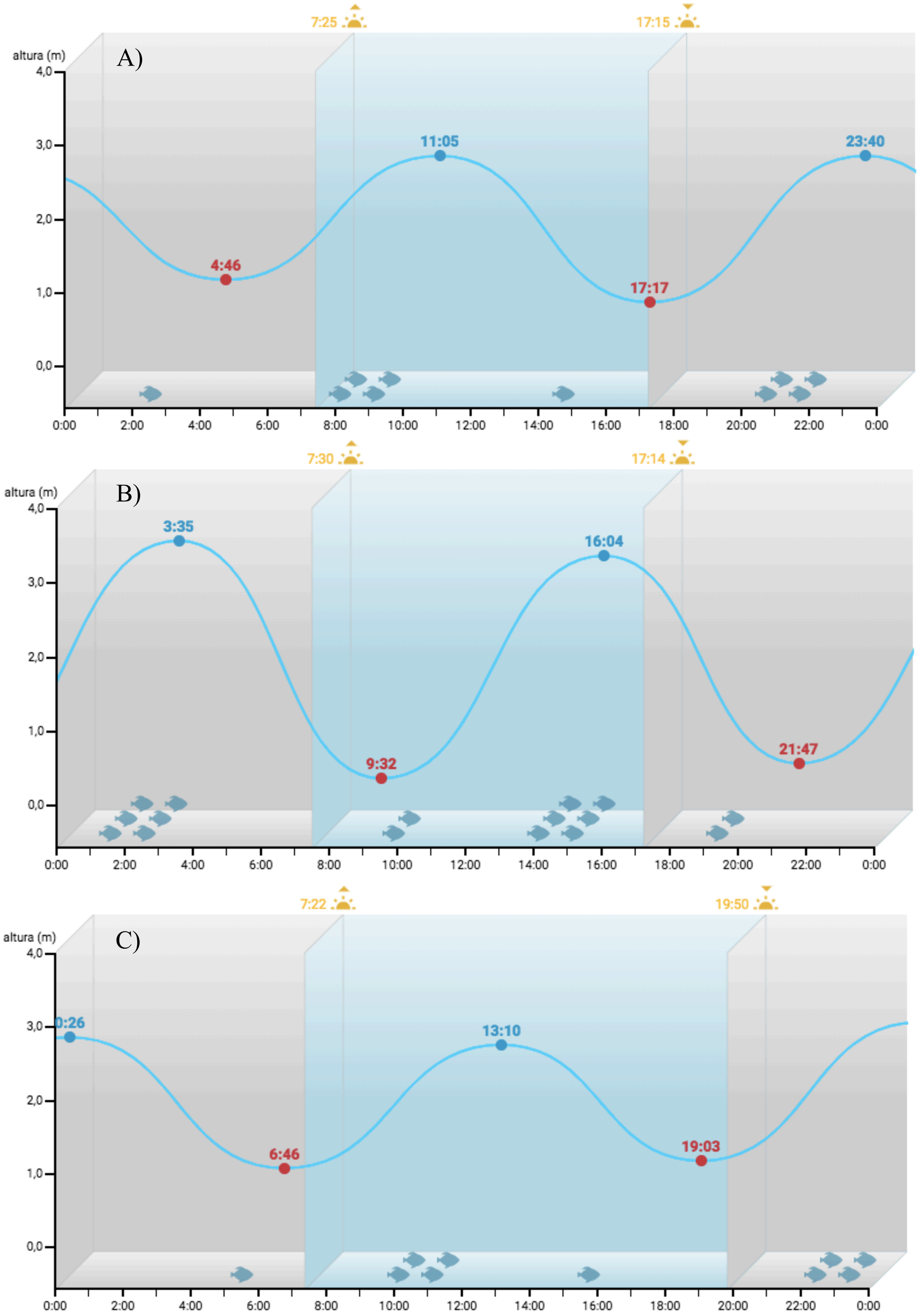


Figure 2.5. Low and high tides in Faro (37.0254 N, -7.9313 W) at Ria Formosa the days A) 30th of November 2021, B) 6th of December 2021 and C) 28th of March 2022 (Source: Tábua de marés, 2022).

2.4.2. Rainwater Harvesting

It is intended to include rainwater harvesting as an alternative water supply in both studied buildings (i.e., the Social Centre and the Primary School). In this scenario, Culatra Island has the help of HYDROUSA, a European Union (EU) Horizon2020 Innovation Action project approved in July 2018 under the topic "Water in the context of the circular economy (Grant Agreement No. 776643)". This project aims to adopt innovative nature-based water management solutions characterised by a low energy footprint to overcome water-related issues (i.e., water supply, water/wastewater treatment and management). These solutions have been demonstrated in three Mediterranean islands (Lesvos, Mykonos and Tinos), achieving promising results in the water sector and society, economy and environment fields. Owing to that, that technology implemented will be transferred to other 25 islands (e.g., Culatra Island) distributed through the Mediterranean region with the participation of 28 organisations (Hydrousa, 2022). Nevertheless, this work has only considered the Social Centre due to the already existence of the required equipment. Thus, the already installed rainwater harvesting system in the Social Centre of Culatra (Figure 2.6) will be improved and modified to promote the reuse of reclaimed rainwater and enhance the efficient use of water. The installed rainwater harvesting system follows the specifications presented in the Especificação Técnica ANQIP 0701, 2009. It counts on gutters to collect and transport water from the roof to the system, pipes to carry water from the reservoir to the building, filters to retain sediments (e.g., sand and leaves), and pumps to propel water through the conductions. Three different rainfall studies were done to evaluate if the dimensions of the already built reservoir were correct and to determine the uses of the reclaimed water depending on the amount of water expected to collect. These predicted uses should always follow the legislation in force (Decreto-Lei 119/2019; Especificação Técnica ANQIP 0701, 2009). Finally, certifications given by the ANQIP are needed to use these systems and the collected water (Especificação Técnica ANQIP 0702, 2021).

Figure 2.6 Existing RHW systems located in the Social Centre of Culatra Island.

2.4.3. Seawater Desalination

To guide Culatra towards a sustainable island, and following the example of other islands, a desalination plant will be installed, but always considering the environmental constraints that might appear in the natural protected area of Ria Formosa, where Culatra is located (Pacheco *et al.*, 2022; Resolução do Conselho de Ministros 78/2009).

Specifically, the solar distillate system that will desalinate seawater in Culatra will be developed by the University of Algarve, and will count with the collaboration of the local company ROLEAR that is already involved in the "Culatra2030 - Sustainable Energy Community" initiative through the installation of the first solar photovoltaic on the island. A small prototype to test the desalination process (Figure 2.7) has been already installed. The system is inspired by an already existed technology tested in Australia called F CUBED (Figure 2.8 A)). The F CUBED technology, widely spread in small communities in the Indian Ocean, Africa and South America, is an innovative version of the already named solar stills, where the height the evaporated water has to travel to reach the transparent surface is smaller compared to the conventional solar stills. F CUBED are panels that require no filters, no membranes, no chemicals and have low maintenance, making them cheaper than other desalination procedures. Moreover, F CUBED is easy to install and operate, although it is characterised by its low efficiency (Solar Water Purifier – Water purification systems, 2022).

Figure 2.7 Solar still built by ROLEAR and installed on Culatra Island

Figure 2.8 F CUBED panels with feed water, freshwater and brine tanks located in different places. A) Example of F CUBED panels installed on the ground. B) Example of F CUBED panels installed on a rooftop, example that Culatra will follow. (Source: Solar Water Purifier – Water purification systems, 2022).

Therefore, as above-mentioned, the system that will be installed in Culatra will be developed by the University of Algarve and will count with the collaboration of ROLEAR. The construction of this system is funded by a grant won in a call for proposals from SMILO (Small Islands Organisation) and Zenon (a Non-Governmental-Organisation that funds sustainable development projects linked with marine ecosystems. Due to the low efficiency of these equipment, to improve it and increase the yield in water production, the system will use the surplus energy produced by solar photovoltaics and store it in batteries, as already some authors indicate (Gude et al., 2011; Gude & Nirmalakhandan, 2010; Kumar et al., 2022; Samuel *et al.*, 2022). The exceeding electric energy produced on the island can provide heat to the system. That heat can be used either to pre-heat the feedwater or to supply more heat (i.e., energy) to the panels. These two situations will help understand whether the feed water temperature or the total heat provided to the panels can improve the system's efficiency. By doing this, the yield in water production is expected to increase from 4,15 L/m^2/day to 4,5 L/m^2/day.

Owing to the location of Culatra Island in the Ria Formosa Natural Park, installing such equipment could damage the ecosystem and disturb the visual amenity that the park offers to tourists (Pacheco *et al.*, 2022; Resolução do Conselho de Ministros 78/2009). Therefore, five systems will be placed and tested on the rooftop of pilot buildings (with the perspective to be then implemented at a broader scale on the island, for example in inhabitant's houses), following the example depicted in Figure 2.8 B). They will produce 100 - 125L/day of freshwater. The freshwater obtained, due to legislative norms (Decreto-Lei 119/2019; Decreto-Lei 152/2017), will be used for non-potable purposes. By introducing this technology to Culatra, the island becomes more sustainable and environmentally friendly. Meaning that carbon emissions and energy costs will reduce since less water is pumped from the mainland to the island, and the island consumes less potable water.

2.4.4. Reuse of Water from the Social Centre's Kitchen

Wastewater in Culatra Island cannot be reused due to the absence of a wastewater treatment plant. The wastewater produced in Culatra is drained, transported to the mainland and treated a wastewater treatment plant. Nevertheless, this work aims to reuse water from some culinary activities carried out in the Social Centre. That is, the amount of water used to wash fruits and other vegetables in the kitchen will be stored and reutilised for the irrigation of gardens and green areas near the Social Centre or even for compost production. To estimate the water that could be reused, firstly it is necessary to know the average water consumed in the kitchen. For that, it was asked to the staff in the Social Centre to measure the daily volume of water, for one week.

2.5. Engagement of Culatra Island's Community

The "Culatra2030 - Sustainable Energy Community" initiative to overcome energy insufficiency and dependency on the mainland was a great success due to the involvement of residents and institutions working together and supporting the project. The communication between the implicated people and their full participation was essential, allowing the selection of the best solutions to be implemented, increasing the final benefits (Pacheco *et al.,* 2022). In the path of water circularity and efficiency, to transform Culatra Island into a sustainable island, this same pattern will be followed.

Therefore, to comprehend and evaluate islanders' position and engagement with water efficiency, to understand their willingness and acceptance to move towards water sustainability and the use of alternative water sources, a questionnaire (Annex C) written and delivered by the University of Algarve together with the Associação de Moradores da Ilha da Culatra was given to Culatra's population, . The questionnaire has a total of 14 questions with multiple possible answers (between 3-5 answers). Questions address different topics: water savings, water uses, recycling, urban wastes, composting, and desalination. Moreover, it has been proven that education plays an important role to accomplish sustainable behaviour toward water. Education is an indispensable element of property and provides skills and knowledge to people (Arora *et al.*, 2022; Gude, 2016; Liu *et al.*, 2013; Neto *et al.*, 2020; Venckute, 2017). Thus, to interact, communicate, inform and involve residents, educational and consciousness-raising campaigns and workshops were also conducted.

3. Analysis of the Results

3.1. Characterisation of the Water Consumption in Culatra Island

Water consumption in the Social Centre

Water consumption in the Social Center was characterised for the years 2017, 2018, 2019 and 2020 (Figure 3.1). Consumptions for the first three years where very similar, reason why an average from those consumption, as well as the standard deviation, was done and plotted. As it can be observed in Figure 3.1 A), the month with the highest water usage was August (33,7 ± 1,5 m^3). For the remaining months, consumptions are very similar, varying between 20 – 30 m^3. The water consumption during 2020 (Figure 3.1 B)) suffers different fluctuations due to the COVID-19 pandemic. March, April and December are the months when less water was used, 7 m^3, 13 m^3 and 15 m^3, respectively. During April and March, due to lockdown, children were not going to the Social Center, and kindergarten teachers and other collaborators were taking turns for maintenance activities. Therefore, the water consumption decreased (i.e., washing hands, flushing toilets, washing vegetables, and use of washing machines). In December, less consumption might be expected due to Christmas holidays. In 2020, the month with higher consumption was September, about 34 m^3, similar to the consumption during August in the other years (33,7 m^3). Finally, the year 2020 presented a total water consumption of 271,0 m^3, with a monthly average of 22,6 ± 7,8 m^3. These values are lower than those obtained for the year 2017 (with total water consumption of 292 m^3 and a monthly average of 24,3 ± 4,0 m^3), the year 2018 (with total water consumption of 312 m^3 and a monthly average of 26,0 ± 4,1m^3), and the year 2019 (with total water consumption of 303 m^3 and a monthly average of 25,3 ± 3,2 m^3) (see Annex A for more detail).

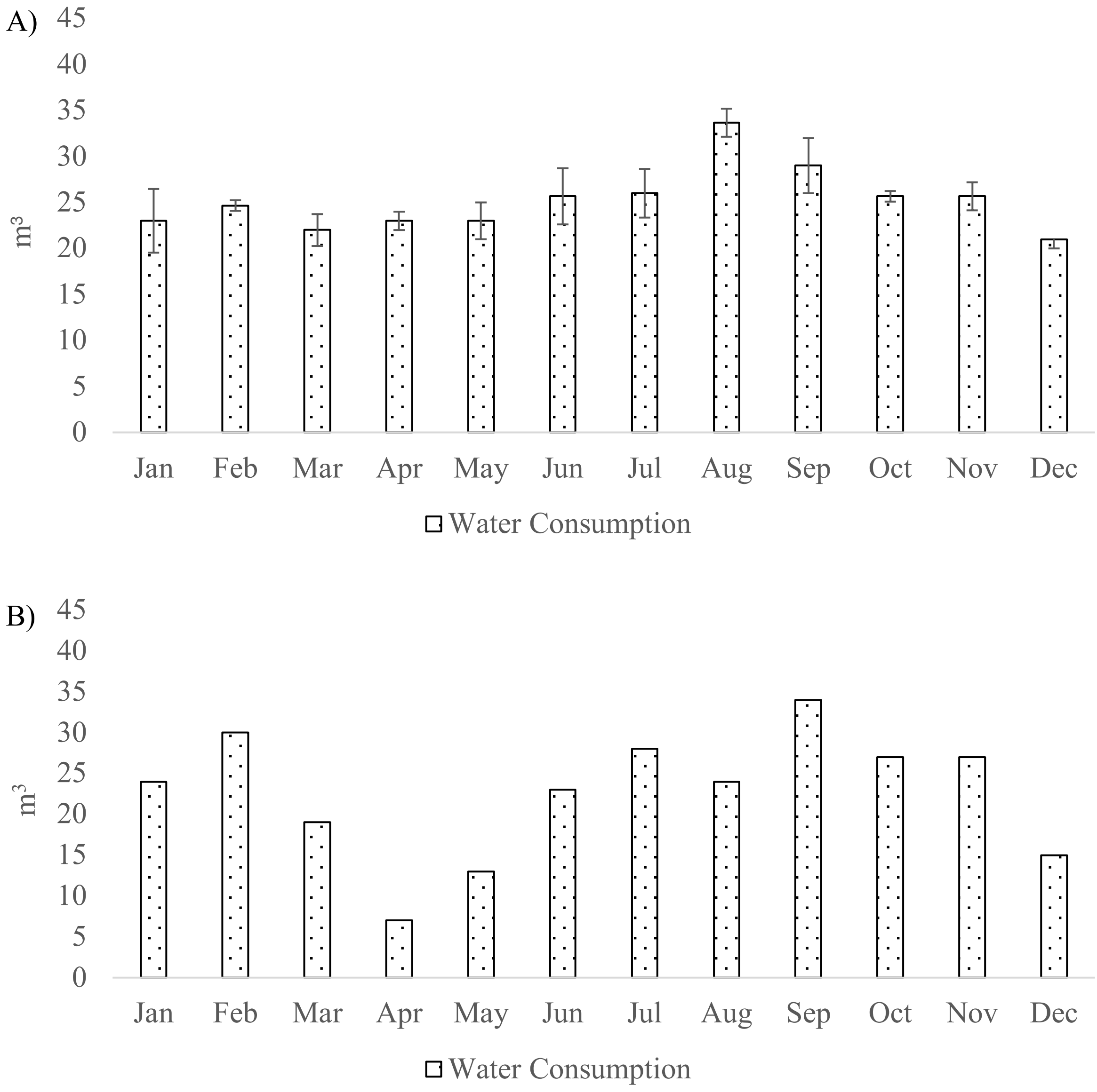
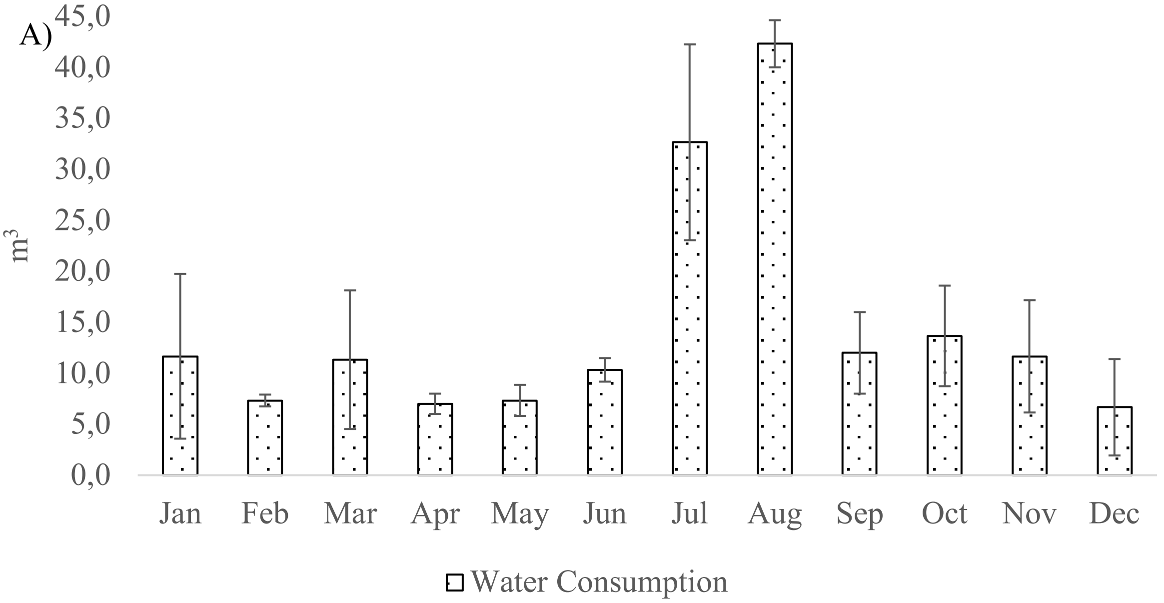


Figure 3.1 A) Average monthly water consumption in the Social Centre for the years 2017, 2018, and 2019 with its corresponding standard deviation. B) Monthly water consumption for the years 2020 in the Social Centre.

Water consumption in the Primary School

Water consumption in the Primary School (Figure 3.2) was also characterised for the same years (i.e., 2017, 2018, 2019 and 2020). Same way as it was done for the Social Centre, due to similarities between the first three years of study, an average and standard devastation was done and afterwards plotted. In the first situation (Figure 3.2 A)), water consumption does not have a clear trend as in the Social Centre (Figure 3.1 A)). Nevertheless, August is again the month when more water was used, with a total amount of 42, 3 ± 2,3 m^3, exceeding the consumption accounted for August but in the Social Centre. It is interesting to point out that in July, in the

Primary School, an amount of 32,7 ± 9,6 m^3 was used, reaching almost the consumption of August in the Social Centre. The water consumption for the year 2020 (Figure 3.2 B)) hugely differs from the other years, even from the other studied building (Figure 3.1 B)). April, May and June were the months when less water was used, 0 m^3, 1 m^3 and 1 m^3, respectively. These results are even contrary to the ones obtained for the same year but in the Social Centre. In the case of the Primary School, no maintenance activities were carried out and, hence, no water was consumed. In 2020, the month when more water was utilised was August, with total water consumption of 14 m^3. Finally, 2020 presented total water consumption of 63 m^3, with a monthly average of 5,3 ± 4,0 m^3. These values are lower than those obtained for the year 2017 (with total water consumption of 179 m^3 and a monthly average of 14,9 ± 9,7 m^3), the year 2018 (with total water consumption of 189 m^3 and a monthly average of 15,8 ± 12,0 m^3), and the year 2019 (with total water consumption of 154 m^3 and a monthly average of 12,8 ± 13,7m^3) (see Annex B for more detail).



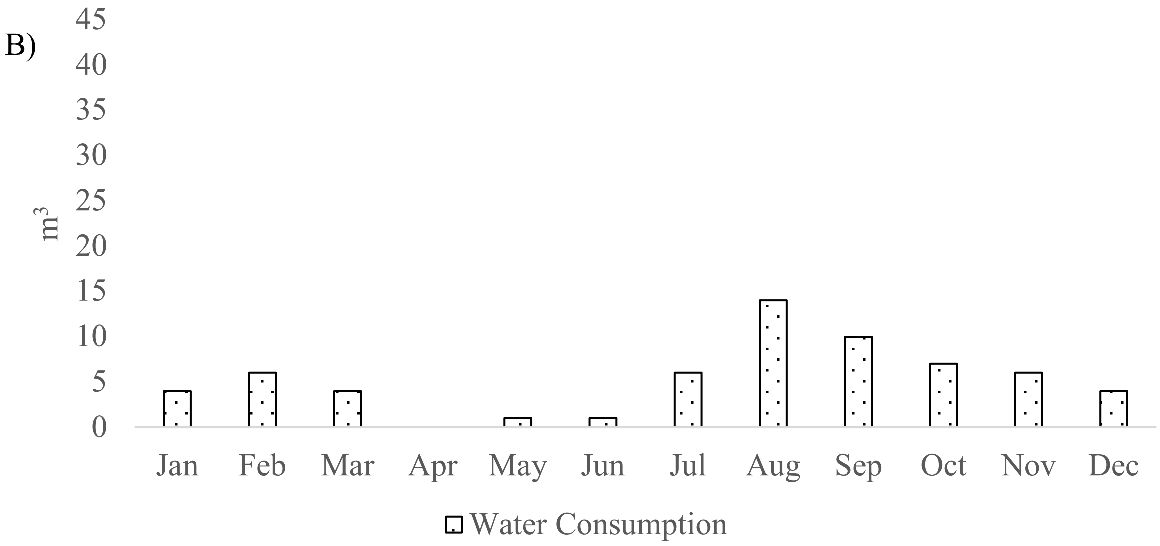


Figure 3.2 A) Average monthly water consumption in the Primary School for the years 2017, 2018, and 2019 with its corresponding standard deviation. B) Monthly water consumption for the years 2020 in the Primary School.

Globally, the Social Centre has a more significant consumption than the Primary School. Specifically, an average of 24,5 ± 4,8 m^3 was consumed during the studied years in the Social Centre (Annex A), whereas 12,2 ± 9,8 m^3 were used in the Primary School (Annex B). The Social Centre counts with a kitchen that makes lunches for the students, teachers and public workers present in both buildings. Therefore, the Primary Schools do not have this consumption, which can explain the less water needed. Moreover, as Table 2.1 shows, for the year 2022, the Social Centre has more students, teachers and public workers than the Primary School. If this trend was also exhibited during the studied years, then less consumption in the Primary School is expected.

3.2. Impact of the Water Flow Reducers' Installation

Efficiency improvement in the Social Centre

The efficiency in the Social Centre was improved by implementing water flow reducers on the 7th of February 2022. A total of 28 water consumption points (taps, toilet flushing and showers) were counted (Table 3.1) in the 7 rooms (6 toilets and 1 kitchen) that constitute the Social Centre. Of those 28 points, 18 were taps located in bathrooms and kitchen, 10 toilets flushing and 1 shower. A total of 19 points out of those 28 were replaced by new equipment: 11 taps, 7 cisterns and 1 shower. After placing such equipment, a significant amount of water was saved.

Results shown in Table 3.2 reveal an average flow reduction of 40 ± 0,2 % in taps, 29 % in toilets flushing and 28 % in the shower.

Table 3.1 Number of equipment replaced by new water flow reducers in the Social Centre.

Equipment	Nº of equipment	New equipment installed	Percentage of equipment installed
Toilet Flushing	10	7	70
Taps	17	11	65
Showers	1	1	100
Total	28	19	-

Table 3.2 Impact of the installation of the water flow reducers on the flow rate of various water equipment points in the Social Centre.

Equipment	Flow rate average reduced	Standard Deviation
Flushing	29 %	< 0,1
Taps	40 %	0,2
Showers	28 %	< 0,1

Therefore, from February onwards, savings in water are expected, aside from savings in energy and financial resources. For a deeper analysis and comparison, further research would be needed (e.g., water bills analysis before and after the implementation of water flow reducers).

Efficiency improvement in the Primary School

The efficiency in the Primary School was improved by implementing water flow reducers on the 7th of July 2022. A total of 8 water consumption points (taps) were counted in the 6 rooms (5 toilets and 1 cleaning room) that constitute the Primary School. This building does not have a shower. The toilets flushing were not considered because of the inexistence of vinyl bags to instal on those water consumption points. For this reason, only taps were considered. Hence, water flow reducers were installed on those taps saving a significant amount of water. An average flow reduction of 40 ± 0,2 % in taps was obtained. Therefore, from July onwards, savings in water are expected, aside from savings in energy and financial resources. For a greater saving, vinyl bags should be placed. For a deeper analysis and comparison, further research would be needed (e.g., water bills analysis before and after the implementation of water flow reducers).

3.3. Nexus between Water and Energy Consumption

In 2018, a total of 75.664,5 kWh/m^3 of energy were needed to abstract and supply water in Portugal. Accordingly to that consumption, 186.891,3 kg of CO_2e/kWh were emitted. To be more precise and representative of the energy consumption in Culatra, an analysis between water and energy was done for the two studied buildings.

Social Centre Analysis

An analysis between water and energy consumed during the years 2017, 2018, 2019 and 2020 in the Social Centre was carried out, using the calculations explained in section 2.3. The graphs shown in Figure 3.3 were obtained from those calculations. A comparison between the energy required to have drinking water and to treat wastewater was carried out, as well as an analysis of the emitted carbon associated with that energy consumption. Due to similarities between the years 2017, 2018 and 2019, and average and standard deviation was done and afterwards plotted. As it can be observed in Figure 3.3 A) the energy required to have drinking water suffers more fluctuations than the energy required to treat wastewater. In any case, as was expected since Figure 3.1 A) already showed a higher water consumption in August, the highest energy consumption was also made in August. Specifically, 10, 9 ± 0,7 kWh/m^3 accounts for drinking water and 5,2 ± 0,2 kWh/m^3 accounts for wastewater. Regarding CO_2 emissions for those three years in August, 29,9 ± 3,0 kg of CO_2e/kWh correspond to the use of energy for drinking water, and 14,3 ± 1,2 kg of CO_2e/kWh correspond to the use of energy for wastewater. Thus, the more energy used, the more emissions.

The energy consumption for the year 2020 (Figure 3.3 B)) suffers more fluctuations due to the COVID-19 pandemic, as expected. March, April and December are the months when less water was used (Figure 3.1 B)) and, therefore, when less energy was consumed. Specifically, in March 3,8 kWh/m^3 were needed to have drinking water, and 1,2Wh/m^3 accounts for energy needed to treat wastewater. Respectively, 1,4 kg of CO_2e/kWh and 0,4 kg of CO_2e/kWh were emitted. In April, 1,4 kWh/m^3 accounts for energy needed for drinking water, and 0,4 kWh/m^3 accounts for energy needed for wastewater. Respectively, 0,5 kg of CO_2e/kWh and 0,2kg of CO_2e/kWh were emitted. Finally, in December, 3 kWh/m^3 accounts for energy needed for drinking water, and 0,9 kWh/m^3 accounts for energy needed for wastewater. Respectively, 1,1 kg of CO$_2$e/kWh and 0, 3 kg of CO$_2$e/kWh were emitted.

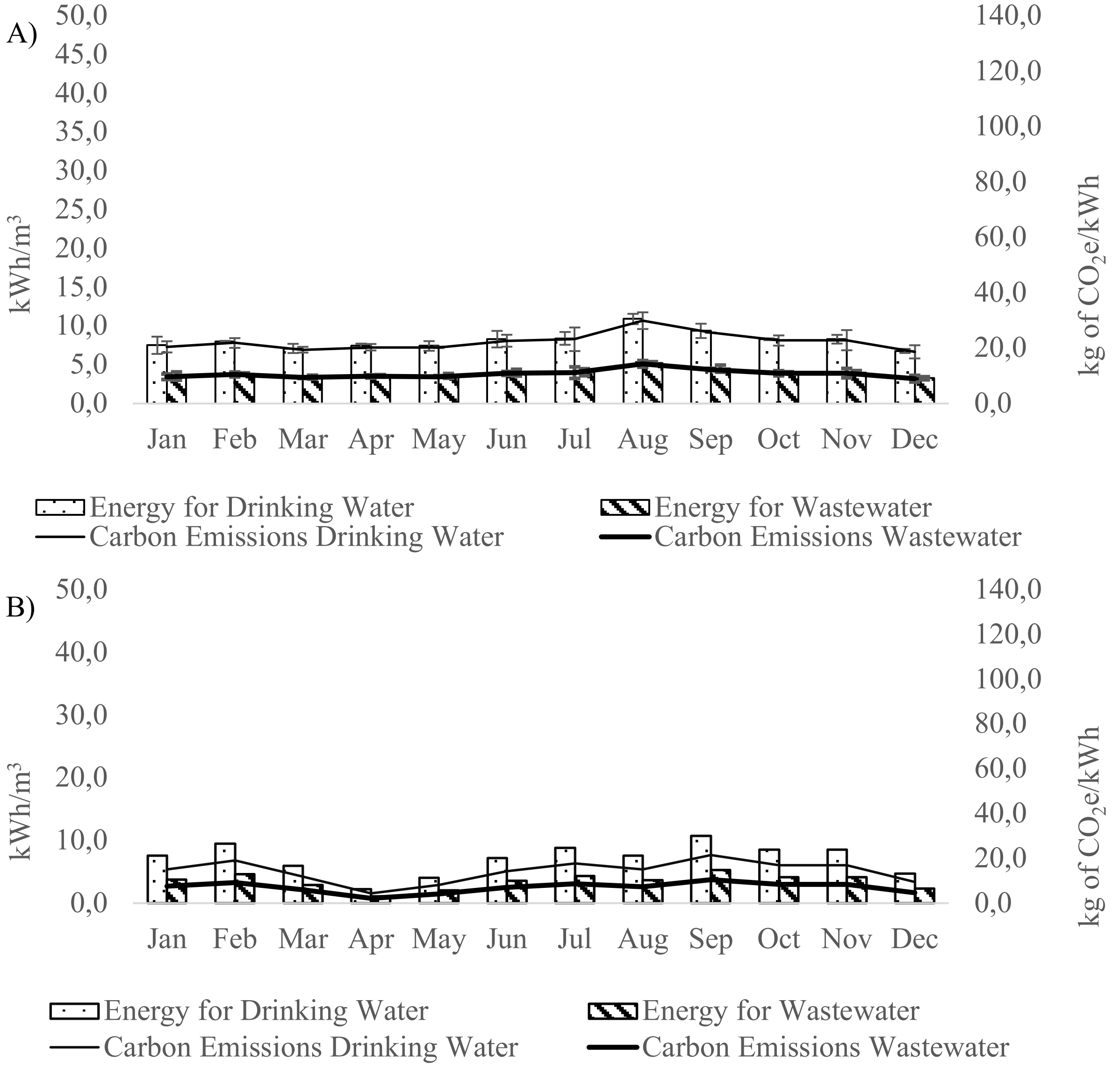
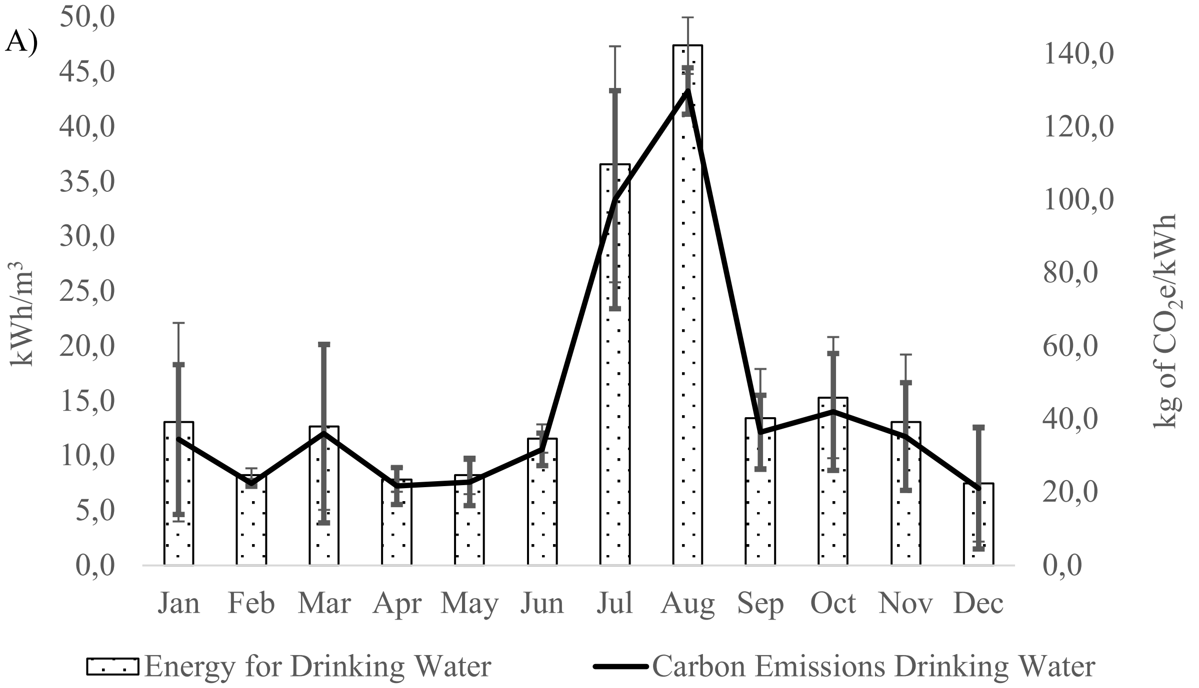


Figure 3.3. A) Average energy required for water abstraction and sanitation for the years 2017, 2018, and 2019 in the Social Centre, as well as their associated carbon emission. B) Energy required for water abstraction and its associated carbon emissions for the year 2020 in the Social Centre.

Primary School Analysis

The analysis between water and energy consumed during the years 2017, 2018, 2019 and 2020 in the Primary School was made using the calculations explained in section 2.3., and following the Social Centre's pattern. The graphs shown in Figure 3.4 were obtained from those calculations. In this situation, values for wastewater are not presented due to the absence of these data. Therefore, only results for drinking water will be explained. As it has been doing in the other chapters, due to similarities between the years 2017, 2018 and 2019, and average and standard deviation was done and afterwards plotted (Figure 3.4 A)). Since the water consumption (Figure 3.2 A)) did not have any trend, the energy consumption does not have any trend either, as expected. Hence, as anticipated, August was the month when more energy was consumed. A total of 47,4 ± 2,6 kWh/m^3 were needed to have drinking water. Accordingly, 129,8 ± 6,4 CO_2e/kWh were emitted.

The energy consumption for the year 2020 (Figure 3.4 B)) suffers fluctuations, as expected, due to the COVID-19 pandemic. In April, May and June, less water was consumed (Figure 3.2 B)), then less energy was used. Specifically, for the month of April, since no water was used, no energy was consumed, and no carbon was emitted. For May and June, 0,7 kWh/m^3 accounts for energy consumption and 0,3 kg of CO_2e/kWh were emitted.



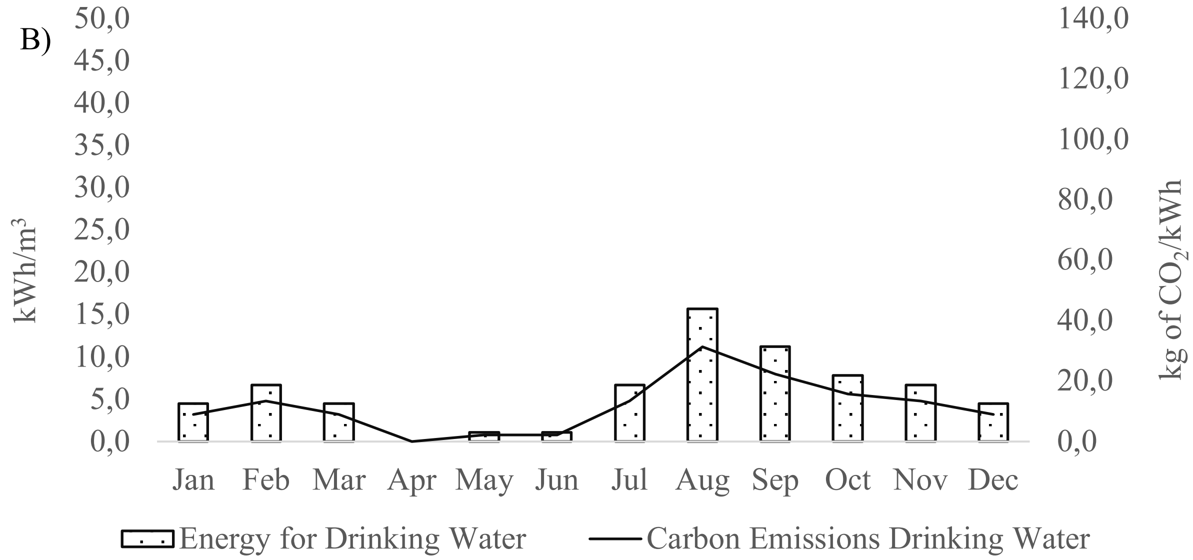


Figure 3.4. A) Average energy required for water abstraction and sanitation for the years 2017, 2018, and 2019 in the Primary School, as well as their associated carbon emission. B) Energy required for water abstraction and its associated carbon emissions for the year 2020 in the Primary School.

Globally, the graphs depicting the data from 2020 (Figure 3.3 B) and Figure 3.4 B)) show how by reducing the consumption of water, a diminishment in energy usage and the associated carbon emissions are accomplished. Table 3.3 also confirms this affirmation. In the year 2020 in the Social Centre a total of 127,1 kWh/m^3 were needed to have drinking water and to treat wastewater. Whereas, for example for the year 2017 in the same building, a total amount of 141 kWh/m^3 was needed. Looking at the associated carbon emissions, in the year 2020 a total amount of 254,4 CO_2e/kWh was emitted, whereas 420,2 CO_2e/kWh were emitted in the year 2017. Once again is proven that by reducing the energy consumption, which indirectly is minimised by reducing the water consumption, less CO_2 is emitted. Hence, if water efficiency is improved in buildings, these results will be achieved. Moreover, indirectly, accomplishments in social, environmental and economic areas will be also fulfilled.

Table 3.3 Total amount of energy required to have drinking water and to treat wastewater, as well as their associated carbon emissions, each studied year in the Social Centre and the Primary School.

		Drinking Water					Wastewater					Drinking Water + Wastewater
		2017	2018	2019	2020	Total	2017	2018	2019	2020	Total	
Social Centre	Energy (kWh/m3)	96,0	101,2	96,0	85,3	378,5	45,0	48,0	47,6	41,8	182,4	561,0
	Carbon emissions (kg of CO2e/kWh)	286,0	249,9	267,9	170,7	974,6	134,2	118,4	132,8	83,7	469,1	1443,7
Primary School	Energy (kWh/m3)	200,5	211,7	172,5	70,6	655,2	-	-	-	-	-	-
	Carbon emissions (kg of CO2e/kWh)	597,4	522,8	481,2	141,1	1742,6	-	-	-	-	-	-

3.4. Analysis of the Possible Alternative Water Sources in Culatra Island

3.4.1. Groundwater Abstraction

The salinity and conductivity analysis and results from the groundwater samples are presented in Table 3.4.

Table 3.4 Water analysis from well samples. Note that there is no sample G when the tide was high; the owner of that well switched the pipeline. Now it is connected to the potable water pipeline instead of the well water pipeline.

	Low tide						High tide					
	Salinity		Conductivity		Temperature		Salinity		Conductivity		Temperature	
Sample	Average (%)	Error	Average (µS/cm)	Error	Average (ºC)	Error	Average (%)	Error	Average (µS/cm)	Error	Average (ºC)	Error
A	0	0	679,0	0	20,7	0	1	0	622,7	1,5	19,5	0,06
B	0	0	374,0	0	19,8	0	0	0	404,0	1,7	19,5	0,06
C	0	0	680,0	0	19,7	0	2	0	645,0	0	19,6	0
D	2	0	2310,0	0	20	0	0,7	0,6	733,0	0	19,5	0
E	0	0	1765,0	0	19,0	0,2	2	0	1259,7	1,5	19,5	0
F	5	0	6420,0	0	19,2	0	5	0	5863,3	5,8	19,5	0,06
G	2	0	527,7	0,5	19,4	0,2	-	-	-	-	-	-
H	3	0	551,3	1,2	19,3	0,2	0	0	552,7	0,6	19,5	0,06
I	5	0	2593,3	4,7	19,3	0,1	0,3	0,6	1039,3	1,2	19,5	0
J	4	0	897,0	0	19,4	0,1	2	0	1039,3	0	19,6	0,06
Average	2,1	0	1679,7	0,6	19,6	0,08	1,4	0,1	1351	1,4	19,5	0,03

Although the tide in the high tide moment is higher than in the low tide moment and, therefore, higher salinity and conductivity are expected in that case, some results presented in the mentioned Table differ from what was expected. Sample D, for instance, has a higher salinity and conductivity in low tide (2 % and 2310,0 µS/cm, respectively) than the same sample but taken in high tide (0,7 % and 733 µS/cm, respectively). Samples F and I show the same conditions. These unpredicted results might be due to infiltration happening into the wells from precipitation occurring those days. Rainwater has minerals, chemicals and other compounds that might affect or dilute the final composition of the groundwater. On the one hand, between the 9th of November 2021 and the 6th of December 2021, when low tide water samples were taken, a total of 9,75 mm of rainwater precipitated (Personal Weather Station Dashboard, 2022). On the other hand, between the 1st of March 2021 and the 28th of March 2022, when high tide water samples were taken, a total of 91,5 mm of rainwater precipitated (Personal Weather Station Dashboard, 2022). It is reasonable to think that rainwater affected the composition of wells D, F and I. Rainwater might have diluted the composition of groundwater, making it less saline when the tide was high. Another hypothesis that could explain those unpredicted results is a saline intrusion. This phenomenon is already happening in some of the wells. Hence, these results evidence that fact.

Groundwater in Culatra is used mainly for irrigation and human-related activities such as cleaning patios. The analysis carried out allows the use of groundwater for those purposes. According to the legislation in force (Decreto-Lei 236/98), groundwater can also be used for human consumption, prior analysis and treatment at a potable water treatment plant. Nevertheless, the average conductivity in high and low tide is higher, in some cases, than the allowed initial value (1000 µS/cm (Decreto-Lei 236/98)) permitted. Water for human consumption is treated in potable water treatment plants, reaching a final conductivity value of 400 µS/cm. However, if the initial value is so high, problems during the treatment might appear. Therefore, to know if the groundwater could be used for human consumption, future research and analysis of other chemicals, physic and biological parameters are needed.

3.4.2. Rainwater Harvesting

The dimensioning of the reservoir, which will contain and store the reclaimed rainwater, is an essential step before building the rainwater harvesting system. By carrying out the corresponding calculations, savings in space, materials and money are expected. For that, it is necessary to know the expected rainfall in Culatra, although precipitation in Algarve is low. Thus, three different studies were carried out to determine which data should be used:

- Data from the meteorological station at the airport covering the years 1971 to 2000. According to Portal do Clima (2022), the average precipitation was 509,10 mm.
- Data from the meteorological station at the airport covering the years 1981 to 2011. According to Portal do Clima (2022), the average precipitation was 511,6 mm.
- Data from the meteorological station at Patacão (Faro) covering the years 2012 to 2021. According to EMA do Patacão (2022), the average precipitation was 565,6 mm.

Due to the proximity of the meteorological station to the island, the trustworthy data from the last 30 years, the easy calculations and the international recognition of the source, the data from the meteorological station at the airport covering from years 1981 to 2011 was selected to do the specific calculations. Hence, the already installed reservoir (Figure 2.6) with a capacity of 18,3 m^3 seems perfect to store the precipitation expected in the forthcoming years in Culatra Island.

In Portugal, reclaimed rainwater can only be used for social and industrial purposes and irrigation (Decreto-Lei 119/2019; Especificação Técnica ANQIP 0701, 2009) (see section 2.4.2. for specific examples). Particularly, the reclaimed rainwater collected in the reservoir located in the Social Centre will be used for irrigation and toilet flushing. Moreover, not only the purposes should follow the legislation in force, but water quality must also be obeyed (Decreto-Lei 119/2019; Decreto-Lei 119/2019).

3.4.3. Seawater Desalination

The results achieved, as well as the performance of the desalination process, will be monitored through sensors developed by the University of Algarve. Measurements of the salinity in the seawater, temperature and energy involved in the process, and yield of water production, among other parameters, will be quantified. The overall monitoring and evaluation procedures will permit identifying and comparing different sets of results and impacts, providing at every moment reliable information to improve.

Although at the moment no physical results have been achieved, a yield in water production of 4,5 L/m^2/day is expected to reach. Taking into account that five systems will be placed on the rooftop of some buildings, a total of 100 - 125L of freshwater per day will be produced. This freshwater obtained, due to legislative norms (Decreto-Lei 119/2019; Decreto-Lei 152/2017), will be used for non-potable purposes. For instance, ice production for fish storage, washing materials from the fishing activities, promoting, in both cases, the main economic activity of the island (i.e., fishing) or irrigating green spaces that will allow preservation and creation of new green areas, increasing carbon capturing and biodiversity.

Apart from the freshwater stream, desalination also produces the concentrated brine stream. This brine cannot be discharged into the aquatic environment due to its high salt content and the negative effect on fauna and flora in the Ria Formosa Natural Park. In the case of the built equipment by ROLEAR, the same way as it happens in conventional solar stills, the salt will be collected at the bottom of the panels and, in the last instance, in a tank. Therefore, the end-use of the brine could be:

1. The salt could be disposed of in an open-air reservoir (Figure 3.5) to be evaporated. Once the water is evaporated, solid salt can be collected in the reservoir. Algarve produces more than 95 % of Portuguese salt, so many selling options are available for the salt produced. This salt, before its sale, has to go through a quality analysis to determine if it can be used for food purposes. Besides this purpose, salt could also be used in cosmetics (e.g., spa/beauty treatments).

2. This brine, instead of being evaporated, could be utilised to water *Salicornia*, a plant that grows in saline environments (i.e., halophytic plant). *Salicornia* is used in cooking and has an attractive commercial value. Nevertheless, the productivity of such a crop must be studied on Culatra's soil and with brine as irrigation water. Usually, the more the saline the environment is, the tastier the plant becomes. Thus, cropping *Salicornia* is a promising way to valorise the brine.

Figure 3.5 Example of a F CUBED installation with an open-air evaporator where salt crystallises. (Source: Solar Water Purifier – Water purification systems, 2022).

This measure will promote the circularity of water and wastes by substituting the primary water demands with another source of water rather than using conventional potable water and by giving a use to the brine rather than discharging it into the aquatic ecosystem, respectively. Moreover, desalination of water will enhance the eco-efficiency in water usage.

3.4.4. Reuse of Water from the Social Centre's Kitchen

Although Portuguese legislation allows the use of wastewater for non-potable usage (Decreto-Lei 119/2019), on Culatra Island does not exist the possibility to reuse this water due to the absence of a wastewater treatment plant. Nevertheless, the island produces a waste of water that can be reused for different purposes, promoting the circularity of water. Specifically, this work focused on reusing the water utilised in the Social Center's kitchen to clean and wash vegetables, fruits and legumes. For that, it was asked to the cooks to measure, with the help of a bucket, the water used for that purpose. The amount of water measured was 67 L/week. This reclaimed water will be collected in a bigger bucket and distributed and used for different purposes.

One usage could be irrigation of plants. If water is available, it exists the possibility to create new vegetated areas near the Social Center. These vegetated areas will be cropped with autochthonous plants, which are distinguished by their lack of water requirements and their survival in the temperate Mediterranean climate of Culatra. Due to environmental constraints and to preserve flora and fauna (Resolução do Conselho de Ministros 78/2009), no other plants can be cropped in Culatra. Nevertheless, it is also possible to crop edible plants that can be cooked in the Social Center and eaten afterwards by students and public workers. In any case, these areas bring different environmental and health-related benefits and several ecosystem services. Green areas clean the air by sequestrating carbon, cool down the temperature and improve water quality. These areas also create jobs, a greater sense of community, help to combat social exclusion and isolation, and strengthen the link with voluntary actions undertaken by the population (Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, 2013).

Another usage could be composting. Composting is the controlled biological decomposition of organic matter carried out either in aerobic (the most efficient composting process) or anaerobic conditions (it generates undesirable odours). The result is a biological stabilised product named compost (Cesaro *et al.*, 2015; Chen *et al.*, 2011). The required organic matter can come from urban solid wastes, in this study case for instance, from food wastes generated in the Social Center. This compost can be applied as soil fertiliser in agriculture, use that is rapidly increasing (Cesaro *et al.*, 2015), or create and fertilise the green areas above-mentioned.

As above-cited, composting implies a biological process where microorganisms are growing. They need the correct environment to survive and thrive. They need organic matter, oxygen and optimal physical and chemical conditions (i.e., temperatures between 55 º and 65 ºC, pH ranges of 6,5 and 8, and moisture contents of 50 to 60%) (Chen *et al.*, 2011). During the process, all parameters might vary or even be consumed. In case needed, conditions can be modified to maintain the system functioning. In a hypothetical situation where the moisture is not optimal and compost is getting dry, extra water can be added to achieve the ideal moisture content (Chen *et al.*, 2011). Is in this situation that the water collected in the Social Center's kitchen can be reused, to maintain the correct humidity during composting.

It is worth mentioning that in this last commented situation, not only the circular economy of water would be enhanced, but also the circular economy of wastes. On the one hand, wastewater from washing vegetables, fruits and legumes in the Social Center's kitchen would be reused to maintain the correct humidity. On the other hand, solid wastes generated in that same kitchen will be given a second life, as well, by composting them instead of throwing them away.

Furthermore, it is intended to not only reuse solid wastes but also the fishing nets utilised on the island, promoting in this situation circular economy once again. The tanks where composting is taking place need to be covered by a net to avoid the appearance of insects and mice. Thus, the fishing nets, which are many since the fishery is the main economic activity in Culatra, would be ideal for this purpose.

In both scenarios presented here (i.e., creation of new green areas and compost production), environmental, social and economic aspects would be enhanced.

3.5. Culatra's Community Engagement

Questionnaires (Annex C) were delivered to Culatra's population in May 2022. A total of 52 families answered this questionnaire, which was collected from them on the 7th of July 2022. From those 52 responses, only 38 were analysed and discussed. Due to invalid and incongruous answers, some had to be eliminated from the total analysis. Hence, the final results are shown in the following figures. Pie charts were chosen to represent the data acquired. Each graph represents the answers given per household to each question:

- It is reasonable to think that the more people living in a household, the more water they consume. Nonetheless, this statement is not always true. In Culatra, 26,3 % (Figure 3.6) of the population consume less than 5 m^3. That consumption is mainly used by households formed by one or two people. The 18,4 % of Culatra's households are formed by one person. Only two households formed by one person consume more than 5 m^3 (between 5- 10 m^3). This is also correlated with the way they use water and their willingness to save it.

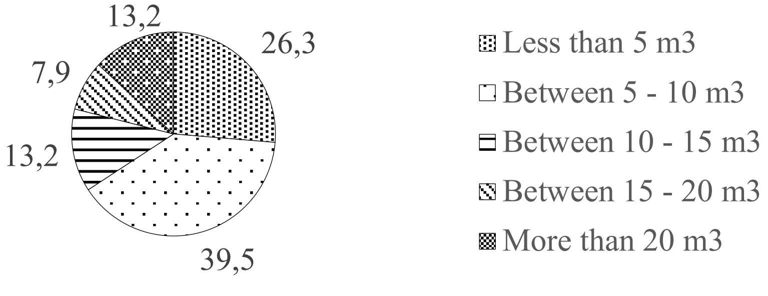


Figure 3.6 Answers to the question "How much water do you consume per month in your home (according to the water bill)?".

- As above-cited, the amount of water consumed by a household is correlated with the number of inhabitants in such household. It is interesting to mention that 21,1 % of the households (Figure 3.7) are habited by 6 people. From this percentage, 2/3 manage to use less than 5 m3 of water. The other 1/3 consumes between 10 -15 m3. It is shown, once again, that not always more people in a household implies more water consumption. As previously mentioned, this is correlated with their use of water and their willingness to save it.

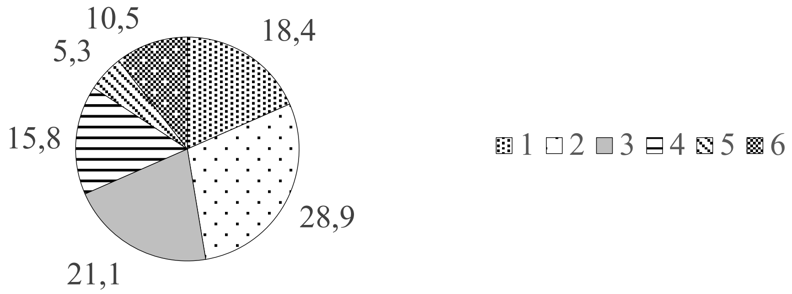


Figure 3.7 Answers to the question "Your family is formed by how many people in the year 2022?".

- Figure 3.8 A) and B) show the usage of tap water in Culatra; if people use it for drinking and/or cooking. It is worth mentioning that a great percentage of people do not drink water from the tap (68,4 %) but, on the contrary, they use tap water for cooking (92,1 %). This result was unexpected. If water has good quality to use for cooking, then it also has good quality for drinking it. Only 11 (29 %) households drink always or sometimes water from the tap and, at the same time, they cook using tap water. Perhaps, Culatra's population is not aware of the water quality on their island. Perhaps they do not know that it is potable. Perhaps there is a lack of communication between administrations and citizens. Perhaps, more workshops and educational and consciousness-raising campaigns are needed.

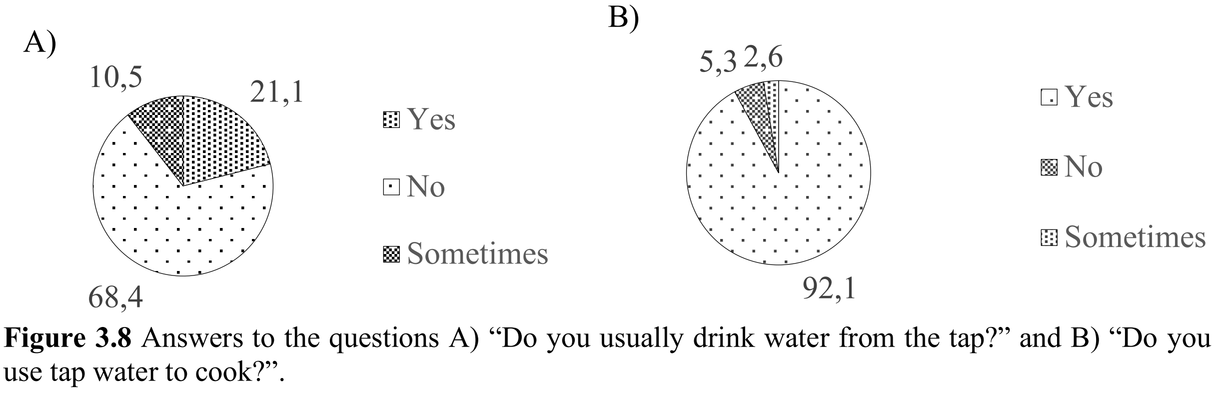


Figure 3.8 Answers to the questions A) "Do you usually drink water from the tap?" and B) "Do you use tap water to cook?".

- Indeed, if a great percentage of people do not drink water from the tap, they have to drink it from other sources. Figure 3.9 reveals that 69,2 % use bottled water. Of that 69,2 %, 15,8% aside from buying bottled water, also drink tap water. Still, it is a huge consumption of plastic and enormous economic waste. Only 10,3 % of Culatra has access to wells as an alternative water source, and 2,6 % have either enough economy to build a rainwater reservoir or enough space. Once again, educational and consciousness-raising campaigns would be worthy to explain the advantages and disadvantages of one and other options to Culatra's population.

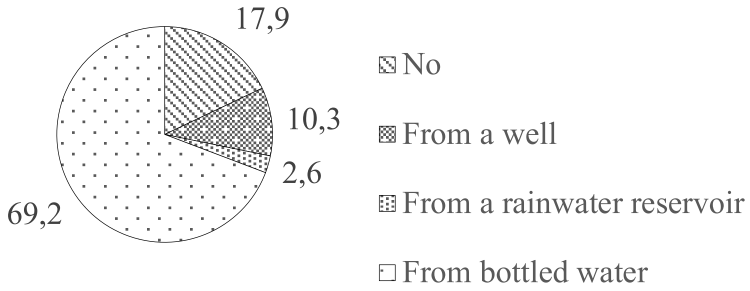


Figure 3.9 Answers to the question "Apart from tap water, do you usually consume water from other sources?".

- Figure 3.10 also supports the idea of giving more educational campaigns and workshops. Half of the population (49 %) does not know where the water comes from. The same percentage thinks water comes from rain, 15 % thinks water comes from aquifers and 5 % thinks water comes from rivers. These answers are correct, water comes from those sources. Nevertheless, only one household knew that water could come from those three sources, although water used in Culatra comes from a river.

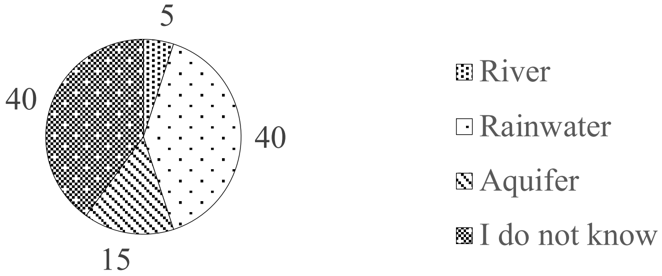


Figure 3.10 Answers to the question "Do you know where does the water come from?".

- In Culatra, it is not often to not have water in the taps (Figure 3.11), according to the 62,2 % of the population. A 23,7 % of the population affirms there is a lack of water in the taps sometimes due to breakdowns in the distribution system. The remaining percentage affirms it is owing to several reasons. The reason why some have experienced a lack of water in their houses might be to the location of their homes. Some might be more prone to lack of water because of maintenance, for example, in the pipeline underneath them.

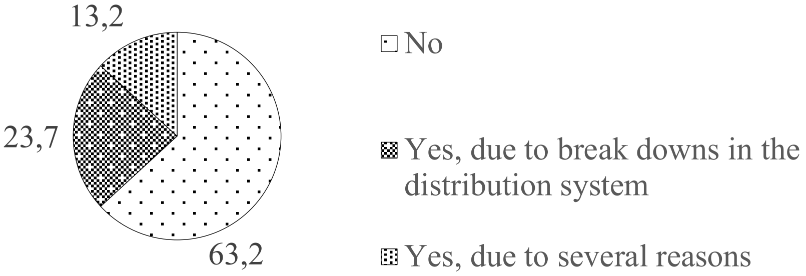


Figure 3.11 Answers to the question “Is it often to not have water in the taps in Culatra Island?”.

- More than half of Culatra’s population thinks they can save more water, in one or another way (Figure 3.12). A total of seven households are willing to implement two, three or all the options here suggested. On the contrary, 32,7 % of the population affirms they save enough water. Of this percentage, 0,76 % consumes less than 5 m^3 per month of water. It is already a low amount of water, so indeed they can already be saving enough water in their homes. Nevertheless, the same percentage, 5,3 %, consumes more than 20 m^3 of water per month. Of course, the consumption depends on the number of people living in the household and their habits, but it is always possible to reduce consumption if there are intentions to.

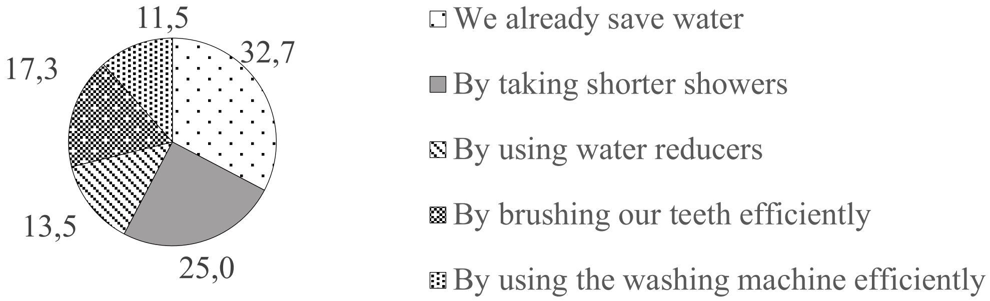


Figure 3.12 Answers to the question “Could your family save more water at home?”.

- In correlation with the previous figure, Figure 3.13 shows the reuse of water in Culatra’s homes. A 39,5 % do not reuse water in their homes, and from this percentage, 15,8 % affirm they already save enough water. Perhaps they do not know ways to reuse water or do not have enough space and money (in the case of implementing rainwater harvesting at their home). Nevertheless, the reuse of water from washing vegetables is well implemented in Culatra’s society. A 37,2 % follow this practice. Maybe just by giving workshops and informing the population about this possibility, this last percentage can overpass the previous one (i.e., 39,5 %).

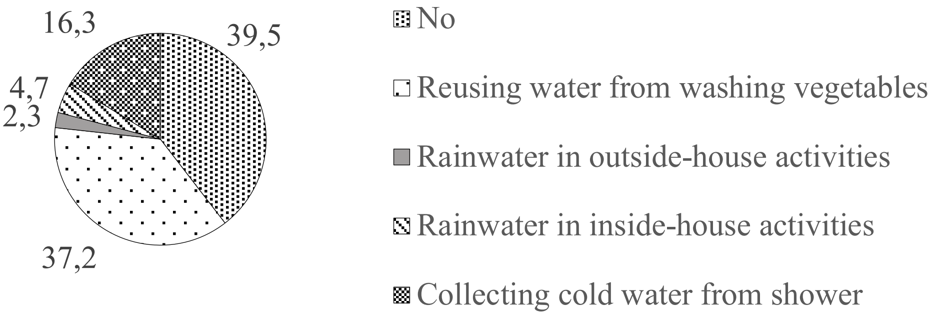


Figure 3.13 Answers to the question "Do you reuse water?".

- Almost half of the population in Culatra (43,9 %) is concerned about water and affirms that is necessary to look for alternative sources of water (Figure 3.14). They agree that any solution (desalinating seawater, harvesting rainwater and/or reusing water) will be favourable. Nonetheless, 14,6 % think that is not needed to invest effort in such activity. In accordance with this last percentage, 5,3 % of the population thinks it is not a good idea to instal a desalination plant in Culatra (Figure 3.15 A)). It was interesting to find that within this percentage, one household was the one which believes it is not needed either to search for alternative water sources or to reuse water.

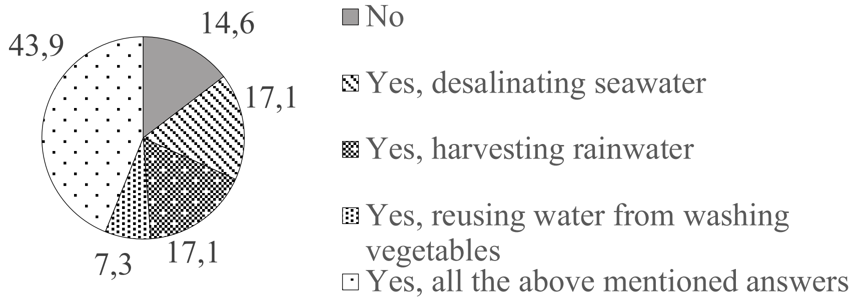


Figure 3.14 Answers to the question "Do you think it is important to search for alternative water sources?".

- Figure 3.15 A) also depicts that 36,8 % do not know whether installing or not a desalination plant in Culatra would be beneficial. Once again, informing the population about the advantages and disadvantages of such technology is crucial. Nevertheless, a great percentage believes such implementation would bring advantages. Specifically, for Culatra's inhabitants, less dependency on the mainland and the opportunity for new jobs on the island (Figure 3.15 B)) are important. But, indeed, such technology brings some disadvantages as well. Culatra is concerned about the elevated costs of the desalination plant and its environmental impacts (Figure 3.15 C)).

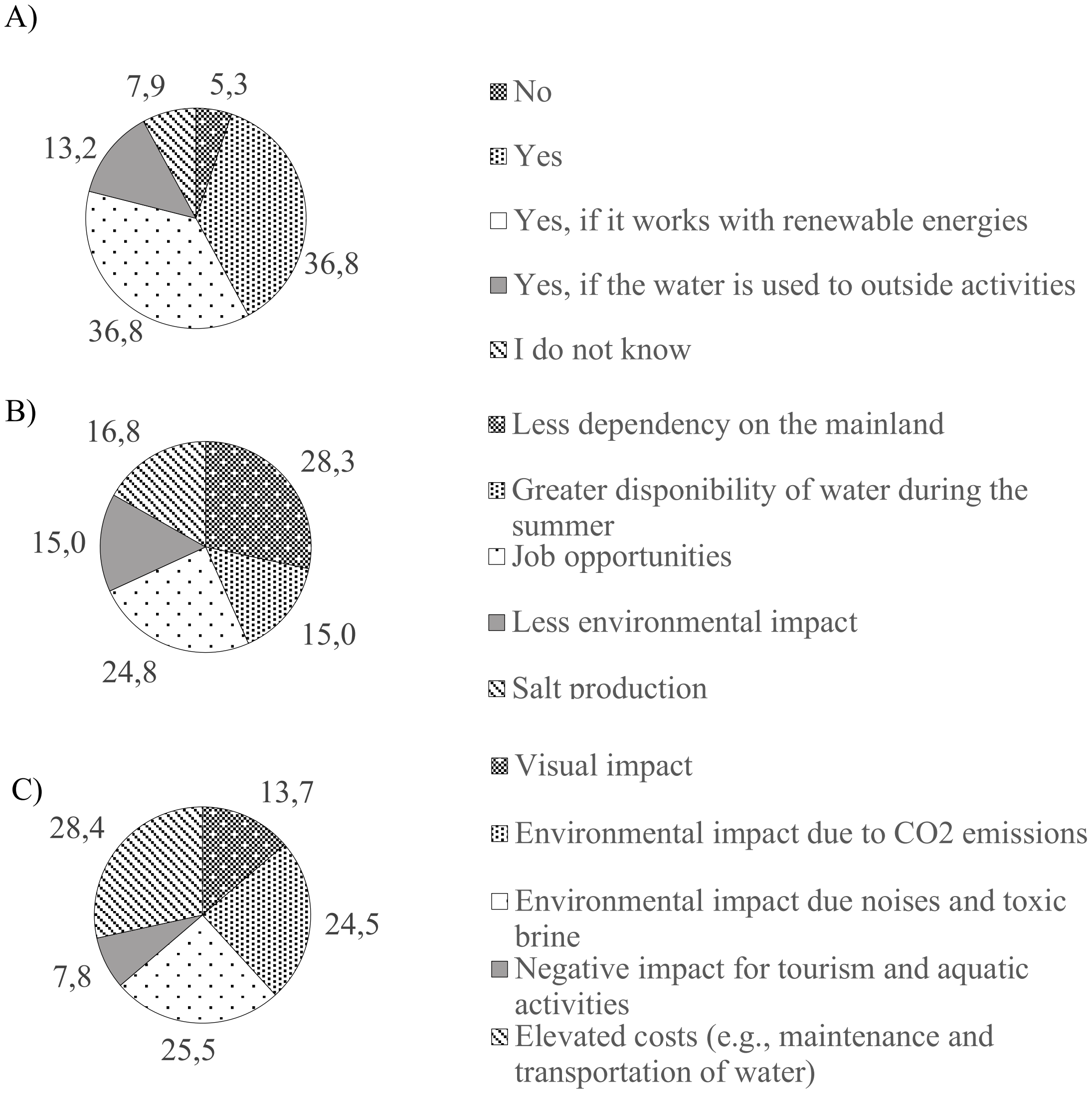


Figure 3.15 Answers to the questions A) "Do you think is a good idea to instal a seawater desalination plant in Culatra?, B) "Mark 3 advantages of installing a seawater desalination plant in Culatra", and C) "Mark 3 disadvantages of installing a seawater desalination plant in Culatra".

- Finally, regarding urban waste management in Culatra, 23,8 % of the population does not want to elaborate compost for several reasons (Figure 3.16). The remaining percentage believes it is needed, and even 40,5 % are willing to learn how to produce it in their own homes.

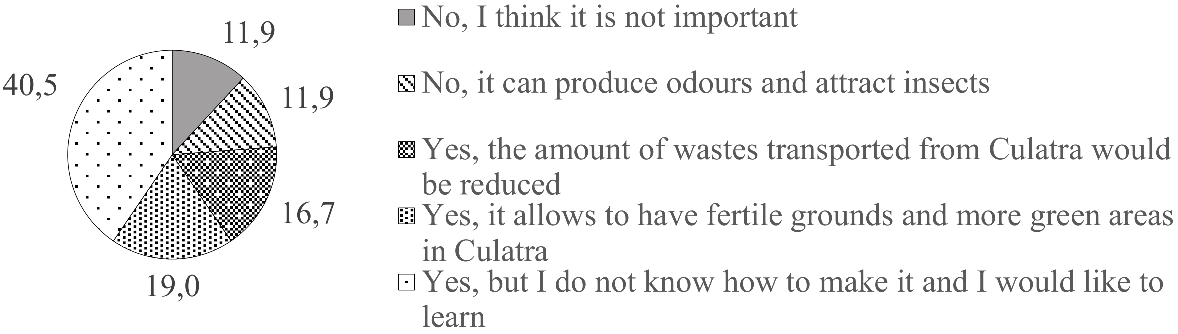


Figure 3.16 Answers to the question "Would you be available to produce compost from organic wastes?"

4. Conclusions

Based on the critical analysis developed in this work, the following main conclusions may be drawn:

- The water consumption from two reference buildings located in Culatra (the Social Centre and the Primary School) was characterised. It was shown that August was the month when more water was consumed in both buildings during the years 2017, 2018, and 2019. Consumptions suffered fluctuations during the year 2020 due to the COVID-19 pandemic. Both buildings were closed, and less water was used. Globally, the Social Centre consumed more water than the Primary School during the studied years (respectively, 23,9 ± 4,8 m^3 and 9,9 ± 0,7 m^3).
- Water efficiency uses in the studied buildings were enhanced by implementing water flow reducers in several water consumption points. At the Social Centre, a water flow reduction of 40 ± 0,2 % in taps was accomplished, whereas, 29 % and 28 % reduction was achieved in toilet flushing and shower, respectively. Regarding the Primary School, only taps were enhanced. A reduction of 40 ± 0,2 % was reached. The next step at the Primary School is to instal vinyl bags in the toilets flushing for greater savings in water.
- The nexus water/energy was studied in Culatra and it was proved that when less water is used, less energy is required and, therefore, less CO_2 is emitted. This was evidenced by looking at the results from the year 2020. Due to the pandemic, less water was utilised, which entailed less energy and fewer carbon emissions.
- According to the results, four alternative water sources can be used in Culatra:
  - ➢ Groundwater abstraction is a valid alternative source of water for non-potable purposes in Culatra Island. Nevertheless, the chemical analysis carried out on the groundwater samples showed that rainwater infiltration might be affecting salinity and conductivity. Special attention should be taken in the future for more intense saline intrusions. For drinking uses, future research and analysis are needed.
  - ➢ The already installed rainwater harvesting system at the Social Centre seemed optimal to collect the amount of rain expected in the forthcoming years in Culatra. The reclaimed water will be used for fit-for-purpose uses. The next step is to build another reservoir at the Primary School.

  - A solar still system, developed by the University of Algarve in collaboration with ROLEAR, will desalinate seawater in Culatra. Different parameters will be monitored by sensors developed by the University of Algarve. A total yield of 4,5 L/m^2/day is expected to reach by storing and using surplus energy produced by solar photovoltaics. The freshwater obtained, as well as the brine, will be utilised for different fit-for-purpose activities.
  - A total amount of 67 L/week is used in the kitchen from the Social Centre. This amount will be used for the irrigation of new green areas and the already existing ones. This will bring different environmental and health-related benefits. Another usage of this reclaimed water will be compost production. Both solutions enhance water circularity and efficiency.
- The success of all these measures depends, in many cases, on Culatra's population. A questionnaire was delivered to Culatra's inhabitants to evaluate their position and engagement within the water circularity and efficiency. Answers were, in some cases, dissimilar. But, globally, it was shown that, perhaps, more educational and consciousness-raising campaigns and workshops are needed so the population have complete information about new projects and measures.

Finally, more research efforts and studies are needed in the future. Notwithstanding, based on the analyses carried out in this work, water circularity and eco-efficiency are improved in Culatra Island when executing the proposed actions.

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Annexes

Annex A –
Calculations (summatory, average and standard deviation) done to the water consumption data from the Social Centre

	2017 Consumption (m3)	2018 Consumption (m3)	2019 Consumption (m3)	2020 Consumption (m3)
Jan	19	25	25	24
Feb	24	25	25	30
Mar	21	24	21	19
Apr	22	24	23	7
May	21	25	23	13
Jun	25	29	23	23
Jul	27	23	28	28
Aug	34	35	32	24
Sep	26	32	29	34
Oct	25	26	26	27
Nov	27	24	26	27
Dec	21	20	22	15

Total	Average	Standard Deviation	Total	Average	Standard Deviation	Total	Average	Standard Deviation	Total	Average	Standard Deviation
292	24,3	4,0	312	26	4,1	303	25,3	3,2	271,0	22,6	7,8

	Total for the four years
Sumatory	1178,0
Average	24,5
Standard Deviation	4,8

Annex B –

Calculations (summatory, average and standard deviation) done to the water consumption data from the Primary School

	2017 Consumption (m3)	2018 Consumption (m3)	2019 Consumption (m3)	2020 Consumption (m3)
Jan	7	21	7	4
Feb	7	8	7	6
Mar	19	6	9	4
Apr	8	6	7	0
May	9	7	6	1
Jun	11	11	9	1
Jul	24	31	43	6
Aug	41	45	41	14
Sep	12	16	8	10
Oct	17	16	8	7
Nov	12	17	6	6
Dec	12	5	3	4

Total	Average	Standard Deviation	Total	Average	Standard Deviation	Total	Average	Standard Deviation	Total	Average	Standard Deviation
179	14,9	9,7	189	15,8	12,0	154	12,8	13,7	63	5,3	4,0

	Total for the four years
Summatory	585
Average	12,2
Standard Deviation	9,8

Annex C –

Questionnaire delivered to Culatra's islanders

A ÁGUA NA ILHA DA CULATRA – O QUE DEPENDE DE NÓS?

Para podermos criar soluções sustentáveis e melhorarmos a disponibilidade de água na Culatra, precisamos de caracterizar as necessidades das pessoas que cá vivem. Por favor, preencha <u>um inquérito por família</u>.

Depois de preenchido entregue na sede da Associação de Moradores da Ilha da Culatra. Obrigada pela sua colaboração!

1. Quanta água se consome por mês na sua casa (segundo a fatura mensal)?

☐ Menos de 5 m^3 ☐ 5 a 10 m^3 ☐ 10 a 15 m^3 ☐ 15 a 20 m^3 ☐ Mais de 20 m^3

2. Nº de pessoas do seu agregado familiar em 2022: _____

3. Sabe de onde vem a água que consome?

☐ Do mar ☐ De um rio ☐ Da chuva ☐ De um aquífero ☐ Não sei qual é a origem

4. Bebe habitualmente água da torneira?

☐ Sim ☐ Não ☐ Às vezes

5. Costuma usar água da torneira para cozinhar?

☐ Sim ☐ Não ☐ Às vezes

6. Para além da água da torneira, habitualmente consome água de outra origem?

☐ Não
☐ Sim, água de um poço
☐ Sim, água de uma cisterna que armazena água da chuva
☐ Sim, água comercializada embalada
☐ Sim, consoante a água que tiver disponível

7. Na Culatra é habitual faltar a água na torneira?

☐ Não
☐ Sim, sobretudo no verão
☐ Sim, mesmo nos meses de inverno devido à seca dos últimos anos

☐ Sim, devido a avarias na rede de distribuição

☐ Sim, por motivos variados

8. Acha que a sua família pode poupar água nas suas atividades diárias?

☐ Acho que já poupamos muita água

☐ Sim, se tomarmos duches mais curtos

☐ Sim, se tivermos autoclismos com 2 possibilidades de descarga, mínima e máxima

☐ Sim, se usarmos copo para lavar os dentes e fecharmos a torneira enquanto os escovamos

☐ Sim, se utilizarmos as máquinas de lavar a roupa e a louça apenas quando estiverem cheias

9. Nas atividades diárias da sua família reutilizam água?

☐ Não

☐ Sim, usamos a água da lavagem dos legumes e frutos para a rega

☐ Sim, recolhemos água da chuva numa cisterna para a usarmos na rega e lavagens exteriores

☐ Sim, recolhemos água da chuva numa cisterna para usarmos dentro de casa

☐ Sim, recolhemos a água fria do duche até ela aquecer e usamos para as sanitas

10. Parece-lhe importante irmos buscar mais água a outras origens?

☐ Não

☐ Sim, dessalinizar água do mar

☐ Sim, recolher a água da chuva

☐ Sim, reutilizar água da lavagem de legumes

☐ Sim, todas as opções mencionadas

11. Está disponível para fazer compostagem a partir dos resíduos orgânicos que produz em casa?

☐ Não, porque não me parece importante

☐ Não, porque pode provocar maus cheiros e a presença de insetos indesejados

☐ Sim, porque permite diminuir a quantidade de resíduos que têm que ser transportados da Culatra

☐ Sim, porque permite solos mais férteis e mais jardins na Culatra

☐ Sim, mas não sei como se faz e gostava que me ensinassem

12. Acha que seria bom para a Culatra ter uma dessalinizadora de água do mar?

- ☐ Não
- ☐ Sim
- ☐ Sim, se funcionar com energias renováveis
- ☐ Sim, se produzir água só para usos exteriores
- ☐ Não sei

13. Assinale os 3 principais <u>benefícios</u> que uma dessalinizadora de água do mar poderia trazer para a Culatra:

- ☐ Menor dependência da água que vem do continente
- ☐ Maior disponibilidade de água para alguns usos nos meses de verão
- ☐ Criação direta e indireta de emprego
- ☐ Menor impacte ambiental do que a água que vem do continente
- ☐ Obter o sal como subproduto, que poderia ser utilizado nas atividades da ilha

14. Assinale os 3 principais <u>prejuízos</u> que uma dessalinizadora de água do mar poderia trazer para a Culatra:

- ☐ Impacte visual, por alterar a paisagem.
- ☐ Impacte ambiental por gastar muita energia fóssil e emitir carbono
- ☐ Impacte ambiental por gerar ruído e produzir uma salmoura tóxica
- ☐ Impacto negativo para o turismo e outras atividades costeiras
- ☐ Ter custos elevados de instalação, manutenção e transporte da água na ilha