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Review

Water Reuse: A Comprehensive Review

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Abstract: Water scarcity has emerged as a pressing global concern, driven by population growth, urbanization, and climate change. As freshwater resources dwindle, the imperative for water reuse becomes increasingly apparent. Reusing water presents a sustainable solution to mitigate scarcity, offering a way to maximize the efficiency of available resources. This review delves into the multifaceted landscape of water consumption and reuse, aiming to provide a comprehensive analysis and understanding of this critical issue. It explores the diverse implications of unregulated water consumption, spanning from its impacts on household routines to its profound influence on economic activities. Additionally, it scrutinizes the legislative framework surrounding water usage, shedding light on the policies and regulations in place. Furthermore, the review investigates the current status of water reuse practices in Europe, delving into various methods of water recovery. Finally, it examines public perceptions and attitudes toward recycled water, offering insights into the societal outlook on this increasingly vital aspect of water management.

Keywords: water; reuse; circular economy

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1. Introduction

In many cases, the term "blue planet" is used when someone refers to Earth. The name is not a coincidence since 75% of it is covered by water. Nevertheless, the overwhelming percentage of it (97.5%) is non-potable, leaving only 2.5% for use and consumption. Despite that, humankind consumes 10 billion tons of water worldwide daily. Already for the first 10 days of 2024, 104 billion tons of water have been consumed [1]. According to the TheWorldCounts database, if the world continues its rampant water consumption at the same rate, the remaining usable water reserves will dry up within 16 years. Therefore, it is prudent to analyze this thoughtless expenditure of water resources and find the main culprits in search of the answer to why our planet is becoming increasingly grey [1].

As far as Europe is concerned, every year an average of 244,000 hm^3 (where 1 hm^3 = 106 m^3) of water is consumed for economic activities. Much of this (11.6%) is consumed by the citizens of the European Union in a domestic context, making proper and easily accessible information, public awareness, and a more generalized, environmentally friendly use of water the only way to a better future [2].

This review aims to define and analyze many aspects concerning water consumption and water reuse to have a clearer and multilayered understanding of the matter. Aspects studied include the variety of implications of unchecked water consumption both within the household and for economic activities, the legislative framework around this issue, the status quo of water reuse in Europe, water recovery methods, and finally, information on the outlook of the general public when it comes to recycled water.

2. The Impacts of Reckless Water Consumption

The way water resources were managed in the past coupled with the inevitable consequences of water scarcity, led to a necessary shift towards a new and different way of managing the existing resources [3]. The—constantly increasing—global demands cannot be met by the available water resources. The result is their gradual depletion. With the crucial role water has in the economy and human activities, a myriad of problems is created.

More specifically, it was shown that water withdrawal, for agricultural, industrial, and urban use, experienced a minimum fivefold increase between 1990 and 2000. Additionally, it is reported that there will be a 55% augmentation up until 2050. Agriculture, in particular, accounts for 70% of global water consumption, with the percentage varying by region. As for Europe, southern countries are more vulnerable, due to the agricultural activities being mainly concentrated there [4].

In America, for example, the areas experiencing significant water scarcity are those where rapid growth of population, expansion of irrigated land, and consequently increased water demand are evident. However, in areas where agriculture was not as developed, this phenomenon is still restricted. Simultaneously, serious issues arose in India, where uncontrolled and unregulated industrial development, combined with overpopulation, led to the deposition of vast amounts of untreated waste in the environment, negatively impacting water quality and public health as well [5]. Apart from these two examples, a plethora of other countries are experiencing similar problems. According to the "Water Security Risk Index", 18 countries are faced with significant water shortage issues, with 15 of them being located in the Middle East [5].

International observations already indicate that approximately 1/10 of the population lacks access to basic drinking water services. With the global population increasing and a lack of initiatives to address the crisis of available water resources, it is evident that the number of people deprived of the fundamental right to water will rise substantially in the upcoming years [6]. This statement is also supported by Figure 1, where it is indicated that the number of urban citizens who encounter water shortage—seasonal or long-term—will continue to increase [7]. Furthermore, it has been revealed that the use of renewable water sources (renewed through the water cycle, for example through groundwater from rainfall) is persistently decreasing. Iceland which holds the primary position in Europe, has halved its usage from 1961 to 2019. In general, if water withdrawal rates are significantly higher than renewal rates, sources will be depleted [8].

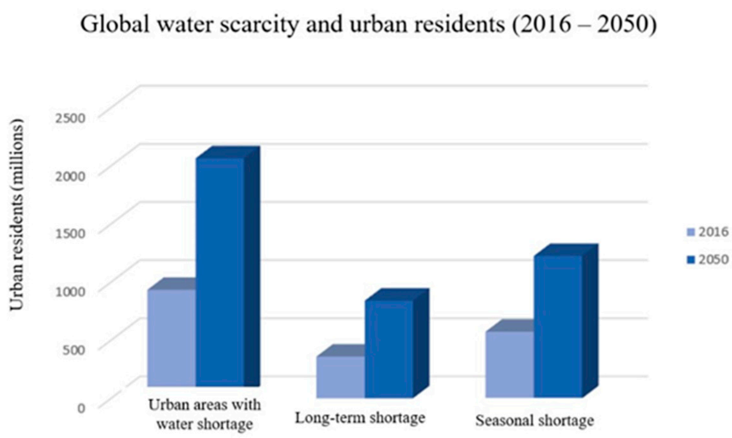

Figure 1. Urban citizens that live under water shortage conditions (2016–prediction 2050) [7].

In summary, chronic water scarcity has been studied as a multidimensional problem. As it was mentioned earlier, this global issue is becoming increasingly severe due to increasing consumer demands, rapid population growth, urbanization, agricultural development, improper utilization of available water, and ultimately, climate change [5]. Therefore, a shift towards water reuse, more specifically a transition towards a circular economy, is deemed necessary.

2.1. The Role of Industry

In Europe, about 215,000 hm^3 of water is used for a multitude of industrial processes [9]. Admittedly, more than half of the quantity (140.00 hm^3) returns to the environment, but without a guarantee for its quality, as most industrial processes pollute the water they use with several substances, which are often dangerous for humans and the environment. In fact, according to Eurostat data, only 60% of the water used at an industrial level is treated before it ends up in the environment [2]. It is no coincidence that many countries of the European Union, such as Greece, Spain, and Portugal already encounter significant drought issues during the summer while the state is unable to manage this new order of things. The problem is not only found in southern Europe but also in countries such as Germany and England, which are experiencing unprecedented levels of water scarcity. In a general context, places with high agricultural activity are the most affected areas when it comes to water stress [2].

This fact is not at all coincidental, as shown in Figure 2, the consumption of water in the agricultural industry amounts to a percentage equal to 41% of the consumption for economic activities [9]. This main source of consumption will continue to exist for many decades to come due to the ever-increasing consumption and increasing need for cultivatable lands, especially in the plains of southern Europe. Therefore, water in this industry is used for several processes, such as the irrigation of crops, the use of it for herbicides and insecticides, and temperature control of the fruits (i.e., heating in the winter months and cooling during summer months) [9]. At the same time, its exploitation is accompanied by several pollutants, drastically reducing its quality. More specifically, these pollutants include the various toxic substances contained in insecticides and herbicides, as well as the various pollutants leaching from fertilizers [10].

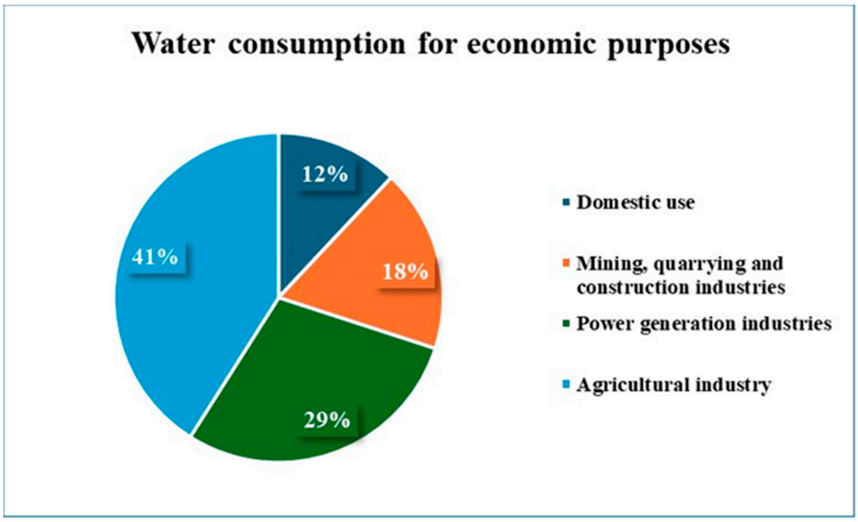

Figure 2. Percentage of total water consumed for economic purposes by industry in Europe [9].

Moving to the next target, the energy production industry is the next to be in the crosshair. Accounting for 29% (Figure 2) of total consumption, water in this industry is primarily used for temperature control of various combustion and nuclear power reactors [9]. In this case, there may not necessarily be significant pollution by substances; nevertheless, the quality of the water is significantly reduced due to the so-called thermal pollution. In this industry, the temperature of the water deviates from the normal limits, causing a significant decrease in the amount of dissolved oxygen in it, due to a decrease in the solubility of the gas with the increase in temperature, negatively affecting fauna and flora after its deposition in the environment [11].

Finally, the mining, quarrying, construction, and manufacturing industries are worth mentioning. Combined, these industries account for 18% (Figure 2) of the total water consumed for economic activities [9]. This percentage may seem small in relation to the industries that have been mentioned before; nevertheless, the keyword in this example is pollution. With the mining and quarrying industry utilizing water in a multitude of processes such as the processing of various minerals, the suppression and limitation of dust, the transport of mud, etc., combined with the very limited treatment of the waste it produces, it is no coincidence that it is a major culprit in terms of water consumption [12]. At the same time, in the context of construction, water consumption is primarily found in processes such as washing machines, preparing, and curing raw concrete, and dust suppression. In this industry, the treatment before final disposal is even more limited, and as a result, the polluted water ends up in the environment contaminated with heavy metals, a high amount of inorganic solids, and derivatives of the various chemicals used [13].

2.2. The Role of Domestic Use

Of course, the industry is not the only one responsible for the uncontrollable expenditure of water resources. As seen in Figure 2, the citizens of the European Union consume about 12% of the total water, i.e., an average of 29,280 hm^3 of fresh water [9]. To put this volume of water in perspective, this amount is roughly equivalent to 7756 Olympic-sized swimming pools. This quantity is divided into several processes that take place in a household, such as water for drinking, food preparation, bathrooms and showers, dishwashers and clothes washers, toilet cisterns, yard irrigation, swimming pools, cleaning, etc. Pollutants that significantly reduce water quality due to the above activities include detergents, pharmaceuticals, chemicals, soaps, large amounts of organic matter, and many others. It may seem that these processes do not consume large amounts of water individually; however, combined, and given that the population of Europe is 746 million, it is not difficult to imagine how this excessive water consumption is built up, stone by stone [14,15].

3. Legislative Frameworks

For a long time, the European Union (EU) has been dealing with problems related to the protection of available water resources by passing legislation limiting reckless waste exploitation but also monitoring the effective treatment of wastewater [16]. The first directive established by the EU related to water reuse is the Drinking Water Quality Directive (DIRECTIVE 80/778/EC) [17]. This directive mainly refers to the implementation of regulations concerning the presence of toxic chemicals and harmful micro-organisms in drinking water. Furthermore, it establishes guidelines when it comes to the determination of physical, chemical, and biological parameters for the various uses of water, especially drinking water. Several pieces of legislation followed Directive 80/778/EC. The various pieces of legislation are presented in the following timeline (Figure 3).

The EU Council Directive (91/271/EC) refers to measures that have to be implemented on a smaller scale, within each community and it aims for more thorough urban wastewater [18]. According to the directive, the secondary treatment of wastewater must be implemented in order to avoid the negative effects that the disposal of untreated wastewater will have on the environment. It also raises the issue of controlling, by general regulations, the channeling of industrial waste into sewerage networks and the disposal of sewage and sewage sludge from municipal sewage treatment plants. More specifically, Article 12 of the directive states that treated wastewater should be reused whenever it is necessary, and disposal methods should minimize adverse effects on the environment [18].

In 1998 and according to Directive 98/83/EC, limits related to the quality of water consumed by humans were established [19]. In 2000, the European Council (EC) enacted the directive (2000/60/EC), which established the water policy framework. The purpose of this directive is to lay down regulations for the protection of inland surface, transitional, coastal, and underground water [20]. The implementation of this framework contributes to many environmental fronts such as ensuring an adequate supply of surface and underground water of good quality, minimizing the pollution load of groundwater, protecting territorial and marine water, and at the same time achieving the objectives of relevant international agreements [20]. The above directive was amended in 2013 according to directive 2013/39/EU of the European Parliament and the Council [21]. The directive adopted in 2006 (2006/118/EC) sets conditions for the protection of groundwater from pollution and degradation. This directive sets limits and quality standards for the chemical and biological status of groundwater as well as for the pumping systems used to transport water [22].

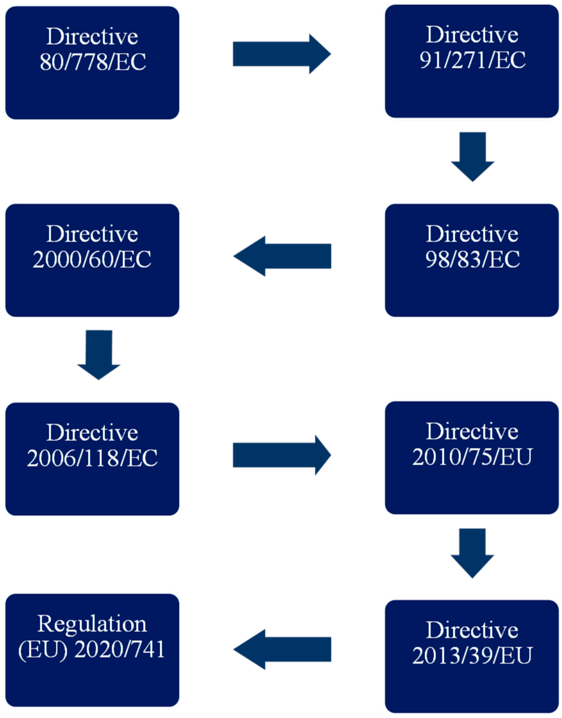

Figure 3. Timeline of European guidelines for water reuse.

Water is the most important factor affecting the sustainability of human life and the planet. Every day, excessive volumes of waste are produced, degrading the quality and quantity of available drinking water [23]. To avoid the significant effects of water degradation, wastewater reuse should be carried out through specific technologies [16]. According to the report published in 2016 by the European Council, only 2.5% of water in Europe is reused [24].

The European Union 2020 enacted Regulation (EU) 2020/741, which sets certain limits connected to minimum requirements for water reuse [25]. The above regulation defines the minimum requirements for water quality in order to preserve water and limit its expenditure. The purpose of the regulation is to guarantee that the reused water is non-harmful for agricultural irrigation, thereby safeguarding the environment, human and animal health and promoting the circular economy, enhancing adaptation to climate change while at the same time helping to implement the objectives of Directive 2000/60/EC, addressing the phenomenon of water scarcity and the consequent pressure on water resources [25].

When it comes to the production, supply, and use of reclaimed water, the qualified authority shall ensure the establishment of a risk management plan for water reuse. Furthermore, the authority is responsible for issuing permits and for ensuring compliance with the regulation. Depending on many factors like geographical position and climate, a Member State according to the regulation is able to decide whether water reuse is required [25].

According to Annex 1 and Section 1 of Regulation 2020/741, reclaimed water can be used in several ways. Water reuse can find application in agricultural irrigation and can be applied in many crops such as edible plants that are consumed raw, edible plants that are processed, and non-edible plants. Furthermore, the water should be reused, always with the protection of the environment, in industrial facilities and in recreational areas [25]. More extensively, for industrial waste and for its recovery and reuse, Directive 2010/75/EU specifies the required prevention and control of pollution from industrial emissions. According to Annex VI, Part 5 of the above directive, the maximum value of total suspended solids for industrial wastewater discharges is set at 45 mg/L [26].

Depending on their quality, the waters are divided into four categories. Table 1 shows the quality categories of reclaimed water, the permitted uses, the indicative technological purpose, and their minimum quality requirements.

Table 1. Reclaimed water quality categories, irrigation method, indicative technological target, and minimum reclaimed water quality requirements [18,25].

Reclaimed Water Quality Class	Indicative Technological Target			Quality Requirements			
	Crop Category	Irrigation Method	Treatment	*E. coli* (Number/ 100 mL)	BOD5 (mg/L)	TSS (mg/L)	Turbidity (NTU)
A	Crops of edible plants that are eaten raw in direct contact with reclaimed water and root crops that are eaten raw.	All irrigation methods	Secondary treatment, filtration, and disinfection	≤10	≤10	≤10	≤5
B	Crops of edible plants are eaten raw and the edible part does not come into direct contact with the reclaimed water. Edible crops that are processed and non-edible crops. Crops used to feed dairy or meat-producing animals are also included.	All irrigation methods	Secondary treatment and disinfection	≤100	≤25	≤35	-
C	Crops of edible plants are eaten raw and the edible part does not come into direct contact with the reclaimed water. Edible crops that are processed and non-edible crops. Crops used to feed dairy or meat-producing animals are also included.	Drip irrigation or other irrigation method that avoids direct contact with the edible part of the crop	Secondary treatment and disinfection	≤1000	≤25	≤35	-
D	Industrial and energy crops and seed crops.	All irrigation methods	Secondary treatment and disinfection	≤10,000	≤25	≤35	-

Circular Economy Model

Thus far, the predominant economic model applied was the linear economy model. A model like that considers used water as waste and operates on the principle of "extract, produce, dispose", as shown in Figure 4a. It exploits water resources, which are later treated as waste, obstructing their reuse even when possible. Essentially, it is an economic system that considers the product's life shorter and thus limited. This conservative model is deemed to be unsustainable in the long term [27].

(**a**) (**b**)

Figure 4. (**a**) Linear economy model; (**b**) simplified presentation of closed-loop water management principles.

Gradually, the transition towards a circular economy model was perceived as the only sustainable path for the environment and the economy. Water naturally exhibits a circular nature through its cycle. Therefore, the application of a circular model that incorporates policies about water usage is feasible, and it provides solutions and promotes ecological water management practices [27].

Before diving more into sustainable water use through this model, a definition should be provided. A circular model is defined as a techno-economic model that advocates for the conservation and enhancement of natural resources and for their increased efficiency. The term "circular economy" became more widely known in the 1960s and 1970s when a redesign of the model of product mobility was needed. However, the exact time of its emergence is not clear. The organization "Ellen MacArthur" played a significant role in promoting and popularizing the concept [28].

This model ought to be applied in the context of water management. A simplified version of its principles is shown in Figure 4b. More specifically, compared to the linear model, it is based on nine strategies: "Rethink, Avoid, Reduce, Replace, Reuse, Recycle, Cascade, Store, and Recover". The first strategy involves reorganizing the way water is used to achieve a more circular approach. The next three strategies focus on reducing the water quantities used. Moreover, the strategies "Reuse, Recycle, Cascade" promote sustainable resource management through continuous reuse. Finally, the last two strategies concern the maintenance and preservation of used water in tanks for future recovery [29]. This results in a system that promotes sustainable development and protects water resources.

For a complete and uninterrupted transition, from the conservative linear model to the circular water management model, certain strategic tools, known as "roadmaps", play a crucial role. They are used by governments to describe the current situation that must change, to set and prioritize goals for the future, and to define a strategy with which the set goals can be achieved. Due to the radical change that must be applied, "roadmaps" should include the idea of water reuse [30]. However, it is observed that many countries that use "roadmaps" for a circular economy do not include the need for water reuse [4].

Therefore, the implementation of a circular economy model—with the additional help of roadmaps—that clearly incorporates water reuse can provide numerous economic, social, and environmental benefits. Among these advantages are the conservation of water resources, increased water availability, its sustainable use, the maximization of the water's value, as well as processes in which it is used, reduced environmental pollution, and an upgrade in the quality of life [4].

4. Water Reuse in Europe

Current wastewater treatment methods allow water of sufficient quality to be recovered for most uses. Therefore, the quality of water used for irrigation must meet certain limits, but without necessarily reaching the quality of drinking water. This way, higher-quality water can be stored or used for domestic applications. In several cases around the world—after appropriate treatment—reclaimed water has been used to provide ecological flows or environmental volumes that consequently meet many requirements set by relevant regulations. Water can be reclaimed for industrial, agricultural, or recreational uses [31].

The use of reclaimed water in agriculture reduces fertilizer consumption since the nutrients contained in these waters can be absorbed into the soil, resulting in a general improvement in crop production. It also provides alternatives for the discharge of treated wastewater in areas where discharge is difficult, such as sites located on public property [4,31]. Despite the advanced technology and the proven benefits of reusing wastewater, there is currently no international norm. There are global reference recommendations—particularly for agricultural use—from the World Health Organization (WHO) published in 1989, with subsequent revisions and extensions [31].

In northern Europe, 51% of reclaimed water is used for environmental purposes (enhancing existing water sources, creating wetlands, etc.), while in southern Europe, it is mainly used for irrigation (44%). Spain, Italy, Cyprus, and Greece are pioneers in the use of reclaimed water in agriculture. Cyprus uses 76% (in 2013) of treated wastewater as irrigation water. In Spain, in 2016, 10% of wastewater was recovered and 61% of this was used in agriculture. Researchers said that with current water reuse applications in the EU, water stress reduction is projected to be only 1% by 2030, although the potential had been estimated at 14%. In Israel, water reuse covers 50% of irrigation water needs, monitors less than a dozen parameters but defines the required level of treatment and crop/product type, and irrigation technique. Italy—on the other hand—sets parameter limits, some of which are stricter than those for drinking water [4].

Spain, Italy, Germany, Greece, and France were the five countries with the highest water reuse volume for the year 2000, and Spain, Italy, Bulgaria, Turkey, Germany, France, Portugal, Greece, Poland, and Belgium are the ten countries projected to have the highest reuse volume in 2050 in Europe. Spain appears to have the leading position in Europe with a projection that it will maintain this position over time. Some other countries, such as Greece, while currently occupying a high position in the ranking, do not seem likely to maintain their position in 2050 [32].

Spain has the highest water reuse volume in Europe and ranks 10th in the world. It shows great variations in the distribution of water resources across its territory and is experiencing water shortages in the southeast [32]. Reclaimed water in Spain is mainly used in agriculture, with more than 40% of all reclaimed wastewater being used for irrigation of pastures, agriculture, woody crops, ornamental plants, nurseries and forages, and products of human consumption in fresh water, among others. Second to agricultural use, irrigation of parks and recreational areas comes second (36% of total reuse), with industry using 10%. It is important to note that, ultimately, reclaimed water makes up 5.4% of total water use in Spain, but this percentage can exceed 25% in certain regions [31].

In Italy, the reuse of wastewater for agriculture (and more recently for landscape irrigation) is the most promising option among the various reuse applications [33]. However, regulated reuse of urban wastewater in agriculture is not yet developed in most Italian regions. The improvement of existing cases of agricultural reuse and the development of irrigation practices requires a reform of the current legislation. More realistic regulations should be established based on the findings of recent research work and experience from the uncontrolled reuse, which is common in the inland areas of southern Italy. The growing interest in wastewater reuse is mainly focused on the control of water body pollution in the northern and central regions, while in the southern regions reuse could have a significant impact on alleviating shortages in water supply, especially in the agricultural sector [33].

In Greece, due to the limited water supply and the high demand for freshwater—especially during the hot season—it is necessary to exploit every possible water resource [34]. Crop irrigation is one of the most intensive consumers of water, especially during the summer. Despite this need, only a few wastewater reuse projects have been implemented, and most of them are pilot projects for crop or landscape irrigation. The most important projects currently in operation are those in Thessaloniki, Chalkida, Malia, Livadia, Amfissa, Kallikratia, and Hersonissos. One of the most important wastewater reuse projects is that of Thessaloniki, in northern Greece. In this project, treated wastewater is mixed with fresh water in a ratio of 1:5, mainly because of the high salinity of the wastewater. Part of the total WWTP of "EELTH" effluent, 165,000 m^3/day is mixed with water from the Axios River for the irrigation of about 2500 hectares of rice, corn, alfalfa, sugar beet, and cotton. Several other projects are currently being planned, such as those in Heraklion, Agios Nikolaos, and various Aegean islands [34].

It should be mentioned that there are several cases of indirect reuse of wastewater from wastewater treatment plants in central Greece. However, the potential for reuse in Greece is limited, since the reuse of wastewater generated by the WWTP in Psyttaleia, Athens, which covers about half of the Greek population, is not economically feasible due to the location of the treatment plant [34].

5. Recovery Methods

The first historical reference to the reuse of water is recorded in 3000 BC in Crete, where the Minoan civilization used its wastewater for agricultural irrigation. The reuse of wastewater finds application even today throughout the world [3]. According to the European Union, 40% of the wastewater produced could be recycled [35]. When the reuse of wastewater is required, then an additional treatment should be carried out to reduce the risks and to ensure the required quality. The main need for extensive wastewater treatment is to remove pathogenic microorganisms and chemical contaminants [32].

Each recovery technology has its characteristics, and it is usually necessary to use two or more technologies to achieve the required water quality levels. The selection of the appropriate process must consider a variety of factors such as the quality and quantity of water in terms of water recovery, the final quality required for the corresponding use, the economic cost, and the environmental impact [32].

Restoration technologies can be classified as conventional and extended technologies. Conventional ones are characterized by the need for large amounts of energy and minimal space. On the other hand, extensive technologies require a large area of land due to the fact that they are based on natural processes, and as a result, the processes occur at natural rates, the energy requirements are very low, and the technologies require low levels of operation and maintenance [32].

One of the conventional recovery technologies and the most widespread is water recycling with membrane processes and more specifically with reverse osmosis. According to new wastewater management research, there are two terms: minimum liquid discharge (MLD) and zero liquid discharge (ZLD) [36]. The MLD concept uses less energy-intensive processes compared to ZLD but can exhibit a high rate of water recycling. Using membrane technologies, MLD can reach efficiencies of up to 80–95%. The ZLD process refers to the complementation of MLD technology with technologies based on thermal thickening, evaporation, and crystallization. The above processes are very energy-intensive, but they can treat wastewater with a high load concentration and reach an efficiency rate almost equal to 100% [16,37]. Membrane technology offers numerous benefits such as high-quality treated water, compact and durable construction, cost-effective operation, and maintenance [38]. Membrane processes such as reverse osmosis (RO) and nanofiltration (NF) are highly effective in removing contaminants from water, including bacteria, viruses, dissolved salts, and organic compounds [39]. This ensures that recycled water meets quality standards for safe reuse. They can be tailored to specific water quality requirements, allowing for flexible treatment options depending on the intended reuse application. Different membrane types and configurations can be utilized to achieve desired water quality standards. While membrane processes require initial investment, they can offer long-term cost savings by reducing the need for freshwater intake and wastewater disposal [38]. The cost of membrane technology has been decreasing over time due to advancements.

Other recovery technologies are through physicochemical systems (coagulation–flocculation), membrane technologies (ultrafiltration), rotating biological contactors, and disinfection technologies (UV radiation, ClO_2, etc.). The above technologies belong to the category of conventional technologies. Extended technologies include stabilization ponds, constructed wetlands, and infiltration–filtration systems [32]. Each recovery technology has its characteristics, and it is usually wise to use more than one technology to achieve the ideal quality performance. The choice of technology must be made based on the quantity and quality of the wastewater to be recovered, the required final quality thereof, the economic cost, and the environmental impact. The directive (2010/75/EU) defines the term Best Available Technique (BAT). This term is applied to the selection of the most appropriate water recovery technique for the specific purpose of its use [26,32].

6. Barriers to Water Reuse

The reuse of purified water leaving a decentralized wastewater treatment plant is mainly applied to the irrigation of agricultural crops—in a proportion exceeding 50% of the total reused water—but also in industry, firefighting, recreational purposes, recharging groundwater resources, water supply for daily domestic use (e.g., flushing), or even for drinking water. However, while in many countries a large proportion of urban wastewater is treated appropriately, very little of the treated water is reused [4,40]. The causes of this finding are technical, economic, institutional (regulatory), and social barriers [4,41].

Regarding the first category, there are a few conditions that need to be met for the treatment of wastewater to be considered adequate and they are related to concentration limits for certain constituents in the effluent. These are inorganic constituents, such as nitrogen (N), sulfur (S), phosphorus (P), chlorine (Cl), and their compounds or toxic heavy metals, such as copper (Cu), lead (Pb), boron (B), arsenic (As) and zinc (Zn), organic pollutants, i.e., compounds such as lipids, proteins, carbohydrates, surfactants, phenols, pharmaceuticals, and pesticides, which are categorized as persistent organic pollutants, but also several other constituents. Other characteristics of wastewater that need to be addressed are pH and pathogenic microorganisms, which are responsible for causing diseases [3]. The combination of primary and secondary treatment is not sufficient to produce water suitable for irrigation, so the tertiary treatment should be included in the design of the plant. Such processes include membrane filtration (ultrafiltration, membrane bioreactors), advanced oxidation methods (chlorination, ozonation, UV radiation), and adsorption with materials that possess high specific surface areas such as granular activated carbon [4,40]. Nevertheless, while these processes achieve high purification efficiencies so that the effluent stream can even be used as potable water, they significantly increase costs. It is expected, however, that advances in the know-how, performance, and operation of the treatment processes as well as the training of the personnel will help to overcome the current obstacles [42].

Most municipal wastewater ends up in large, decentralized plants located at low altitudes so that it can reach them by gravity and thus lower the energy costs for pumping. Obviously, the reclaimed water cannot be distributed either through the sewage network or the water supply and irrigation network. Consequently, its transfer to the crops requires not only operating costs but also the construction of a new distribution network that must cope with the huge distances between the arable land and the wastewater treatment plant, cross-connection issues with other networks, and proper management of the water distribution [4,42,43].

It has been argued that the institutional barrier may have an even more catalytic effect than the aforementioned category. Insufficient information and, possibly, awareness among policymakers contribute to the ineffective legislative infrastructure. Water quality is vital for the good quality of crops and therefore the health of consumers. Water quality criteria must therefore be strict, without at the same time making it impossible to achieve a circular economy. The examples of Israel and Italy are illustrative, where the former has more flexible legislation, also related to the type of crops, while the latter has limited reuse due to strict regulatory provisions. Legislation should keep pace with research progress which is constantly being applied to existing processes. In turn, applications feed the research sector with valuable data, thus creating a constructive perpetual cycle. However, there is often disagreement between stakeholders (e.g., agriculture and wastewater treatment), which discourages public opinion [4,44].

European regulation 2020/741, which sets limits for Total Suspended Solids (TSS), turbidity, Biological Oxygen Demand (BOD), and Escherichia coli bacteria, is an attempt to establish a common policy to ensure the quality of water for irrigation and to inform citizens. Nonetheless, the number of EU Member States opposed to the reuse of reclaimed water has not been reduced to zero [4,25,44]. In the US, water reuse is gaining momentum due to alarming data on the availability of conventional water resources. Interestingly, the regulations between different states—even those that are adjacent—show great disparity. Thus, it is suggested that the need for reuse—expressed through more lenient provisions—is a very localized problem that usually stems from the low availability of conventional water resources. Finally, common to all states is that the statutory treatment requirements show a gradation depending on the use of the reclaimed water [44].

It is a fact that water reuse is not widely accepted by society. One reason for this is the lack of public awareness of this unprecedented practice of the circular economy model. Consumers' concerns relate to the use, cost, quality (odors, color), and lack of confidence in the proper functioning of waste treatment plants [41,42]. For their part, farmers are wary of its use for reasons related to its stable levels of quality, risks regarding the quality of crops and land, and the commercial value of the products produced. Potential financial facilitation in the supply of reclaimed water and the fact that its high content of nutrients such as nitrogen and phosphorus reduce the need for fertilizers are two reasons that may draw their attention to it. To consolidate water reuse, consumer awareness should go hand in hand with the production of goods from crops irrigated with that kind of water. The contribution of the academic community can play an important role here [4].

7. Acceptance

The following paragraphs analyze research carried out in America, Europe, and Greece. The purpose of these questionnaires was to record and draw conclusions regarding the acceptance of the human population regarding the inclusion of reclaimed water in their daily life.

7.1. Acceptance of Water Recycling in the USA

The goal of this research is to explore the factors that affect underlying public reluctance toward using reclaimed water. The initial goal was to ascertain, through a more qualitative method, the elements that individuals self-report as being significant in their decision-making regarding water recycling. The second goal was to employ a multivariate technique to assess the degree of correlation between expected dislike toward recycled water and willingness to use it, while also accounting for many theoretically significant individual difference characteristics [45].

Using questions developed on a five-point Likert scale ranging from 1 "strongly disagree" to 5 "strongly agree", participants expressed [46]:

(1) Their willingness to drink different water alternatives.
(2) Their trust in different public/private/government/non-profit organizations related to drinking water.
(3) Their willingness to implement water reuse for indoor/outdoor activities.
(4) Willingness to pay for drinking water/wastewater reuse.

Numerous crucial elements for gaining public acceptance have been discovered by the substantial literature on water recycling [47,48]. Specifically, it has been shown that unpleasant emotional responses—also referred to in the literature as the "yuck factor"—have a significant influence on how society as a whole and individuals make decisions regarding water recycling [46]. When adjusting for other factors like environmental and risk attitudes, trust, social pressure to support the scheme, and perceived control, Nancarrow et al. [49] demonstrated that emotions, in this case, reports of general negative or positive feelings toward a water reuse scheme, predicted willingness to use recycled water at the individual level. According to Haddad et al. [50], there was a strong correlation between the readiness to utilize recycled water and psychological characteristics such as sensitivity to concepts of disgust and contagion. In a more recent study, after adjusting for individual differences and political party identification, negative emotional responses toward water recycling were specifically linked to degrees of pathogen disgust sensitivity, or how quickly one becomes disgusted by stimuli connected to infections [51].

The impact of expected distaste on the desire to utilize recycled water for higher contact uses (drinking), even after adjusting for other significant variables (demographic, experiential, attitudinal, and ideological), remains to be determined. It has been discovered that certain demographic traits, such as gender, age, and educational attainment, predict the perceived risk connected to water recycling. Research focusing on this topic has generally shown that older people, women, and people with lower levels of education believe that recycling water poses a greater risk. It should be highlighted, although, that results of demographic associations vary throughout research and situations [47]. In numerous research, practical considerations like price and the quality of the water have also been shown to be significant [52].

Personal beliefs and attitudes seem to be important as well. In certain situations, acceptance is predicted by environmental awareness and pro-environmental sentiments [45]. Numerous studies have revealed that the general public believes that water recycling is harmful to public health and beneficial to the environment [53]. Therefore, depending on how the general public conceptualizes water recycling, prosocial ideals may lead to contradicting outcomes. The acceptance of water recycling may be influenced by ideological factors, such as moral reasons. In many groups, the perceived religious purity of the water recycling technique may hold significance [45]. Previous experience could also be significant; consuming tap water has been linked to less emotional distress when considering drinking recycled water [51].

The heterogeneity brought about by various water reuse techniques adds to the confusion surrounding the criteria that matter most when making judgments about water recycling. One of the best indicators of attitudes toward water recycling is the extent of "bodily contact" with reclaimed water. Numerous studies have shown that "low contact" usage, such as flushing the toilet, is more acceptable than "high contact" uses, like drinking or taking a shower [46]. Furthermore, depending on the type of water being treated (e.g., grey versus black water; indirect versus direct potable reuse), the perceived relationship between recycled water and bodily products (e.g., feces) may differ between water reuse methods. Crucially, discomfort with contamination is strongly predicted by the idea of bodily products [54], especially when there is a lot of physical interaction. It is challenging to compare research examining attitudes toward specific water reuse methods since the degree of bodily contact and perceived association with body products frequently vary from context to context. This makes it challenging to identify what factors are most crucial in boosting acceptability. From a policy perspective, it is especially crucial to increase acceptance of high-contact uses, such as drinking recycled water, as restricting recycled water's use to low-contact applications might either severely limit its potential applications or need costly pipe upgrading [46].

In the literature on water reuse acceptance, there is debate over whether it is beneficial to concentrate on the "yuck factor" [45]. This framing, according to Russell and Lux [55] is restrictive because it presents the general population as emotional and irrational in contrast to more "rational" expert viewpoints. Studies that show that disparities in opinion between the general public and scientific specialists are not as great or unbridgeable when communities are involved in governance lend credence to this claim. Furthermore, according to Russell and Lux [55], the "yuck factor" narrative suggests that public opinion is set and that responses to disgust are unavoidable. Rather, they contend that the key to raising acceptance is a strategy centered on fostering public conversation and trust. Additional research on water recycling has indicated that institutional and cultural, value-based elements are crucial for winning over the public, which lends support to this strategy [56,57].

The extent to which these two strategies might actually be complementary rather than mutually incompatible is unknown.

7.2. Social Acceptance in Europe Regarding the Reuse of Treated Water in Specific Applications

In this section, an attempt is made to outline the level of social acceptance of the reuse of treated wastewater and gray water in applications such as agricultural irrigation and domestic (toilet flush, garden irrigation) or recreational (park, golf course irrigation) use. Survey data for regions of Europe are analyzed. It is important to mention that although the most recent European directive (2020/741) from the European Commission sets the minimum requirements for the implementation of water reuse systems, nevertheless, many EU states have not made decisions to implement the directive due to factors such as differentiation of the legal system depending on the region, water management problems and/or social acceptance [58].

A total of 54 farmers/growers in Reggio-Emilia in Emilia-Romagna (Italy) participated in a related survey on the social acceptance of water reuse applied to cropland irrigation [59]. At that time, the local Wastewater Treatment Plant conducted a water reuse project that not all respondents were aware of. However, over half had a positive view of the water quality in the area [59]. Overall, 93% of the farmers had a positive view of the quality of treated water. The perceived risk (e.g., for health, environmental, etc.) of water reuse cultivation emerged as a catalytic factor influencing acceptance.

Additionally, certain crop types tended to be more accepted than others, such as growing alfalfa as opposed to tomatoes. Some farmers (46%) recognized the advantages of water reuse, especially those who were informed about the reuse project [59]. The research confirms the relationship between low educational levels and the perception of fewer advantages and therefore less acceptance. In summary, research reveals that reduced risk perception is associated with increased acceptance without necessarily identifying specific benefits. At the same time, it sets the framework of water scarcity and climate change around the issue, but also covers the future needs of water users [59].

In France, the reuse of treated wastewater is not a common topic of discussion, nor is it covered by the media [60]. However, 70% of consumers of agricultural products in the Pic Saint-Loup region in the south of France who took part in a related survey would agree with its application in the irrigation of products such as fruit and vegetables and 90% with the irrigation of green areas (e.g., parks) (Figure 5). Research confirms that consumer acceptance increases by providing “neutral” information about the issue. Furthermore, it is confirmed that factors such as awareness of environmental issues and perceived health risks play an important role in shaping acceptance [60]. It is recommended to initiate intensive, targeted information campaigns and to deepen studies, including taste tests (as a significant minority show some inconsistencies between attitudes, food purchase intentions, disgust, and perceived risks).

Evidence from Mesa-Pérez et al. [61] collected from eight European Union countries (Belgium, Bulgaria, France, Germany, Greece, Spain, Italy, Portugal) identify (a) the high cost of reclaimed water for farmers and (b) the societal distaste for products irrigated with recycled water as key factors in the applicability of reuse systems and as a cornerstone of the EU strategy to promote the use of reclaimed water in agriculture [61].

The example of domestic gray water treatment and reuse systems comes from a group of households in the Sant Cugat del Vallès District in Barcelona, Spain [62]. In this case, too, the most critical factor affecting acceptance emerged as the perceived health risk, which most users (>90%) rated positively or neutrally. However, the reuse systems implemented did not perform optimally, resulting in dissatisfaction among many users. In many cases, the dissatisfaction was outweighed by the positive consequences for the environment. The cost of the systems in this case did not play a particularly decisive role in acceptance, in contrast to the level of information that was negatively evaluated. The estimated level of acceptance was 72% of experienced users (Figure 5) [62].

Students in Germany who had no previous experience with reuse systems showed acceptance especially for applications such as watering plants and the garden, flushing the toilet, or washing the car [63]. Showering and drinking water received the least acceptance. The perceived health risk was judged to be a determining factor, and higher educational level contributed to a greater likelihood of acceptance [63]. In addition, knowledge of possible unplanned reuse led to a higher level of acceptance of planned reuse. Factors shaping acceptance included vocabulary and level of information about recycled water, as well as emotional factors (e.g., disgust). The research concludes that applying quality standards similar to those of drinking water and the educational preparation for outreach education could lead undecideds to acceptance.

A study by Lyach et al., 2023 [64], correlates water savings methods with the reuse of treated greywater in Czech households (Figure 5). Although the majority of respondents practiced saving methods, only 17% viewed reuse positively. Households would accept water reuse in toilet flushing, car washing, room cleaning, and lawn watering, but not in activities involving contact with water [64]. Hygiene emerged as the most important factor influencing acceptance, while comfort and practical utility were also considered important. Lack of understanding of water purification technology as well as trust are factors influencing acceptance. The "eww" effect for treated gray water is, also, strong among the Czech public.

In summary, from the above research, we conclude that the acceptance of the reuse of treated water (grey water, wastewater) is directly influenced by similar factors regardless of the region of Europe for which the study is conducted. At the same time, complementary factors are being considered depending on the specific applications of water reuse. The role of demographic characteristics (age, gender, level of education, etc.) is not confirmed in all studies. Primarily, the most consistent catalyst factor that appears to have a dominant effect on the level of acceptance is perceived health risk. Secondarily, other factors that are considered important are environmental awareness, disgust, the information provided, and cost.

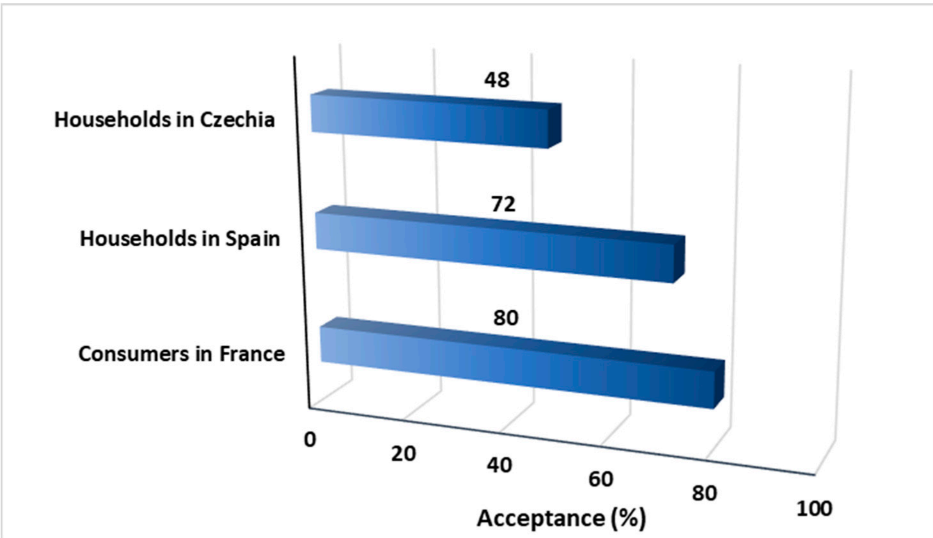

Figure 5. Acceptance of water reuse in different applications [60,62,64].

7.3. Acceptance of Water Reuse in Greece

Water scarcity and droughts are likely to deteriorate further due to increasing human activity and observed climate change. Over the last few years, drought phenomena have increased significantly in number and intensity in regions of the European Union, affecting approximately 11% of the population. Greece (especially its southern part and islands) is one of the Mediterranean countries that is expected to suffer severe water scarcity problems in the upcoming years [65].

Water originating from the treatment of mainly municipal waste has already emerged as a reliable source for various activities and uses. In Greece, more than 492 Wastewater Treatment Plants (WWTPs) produce wastewater with high reuse potential. Greece is a country that implements water reuse, mainly for crop irrigation. Recycled water is primarily used in semiarid areas where the phenomenon of water scarcity is more intense. The most important water reuse projects that have been implemented are located in the area of Thessaloniki, Chalkida, and Hersonissos, in Crete [66–68]. Specifically, according to data from the Hellenic Association of Municipal Water Supply and Sewerage Companies, until March 2023, approximately 10.95 hm^3/yr of recycled water was used in Greece, of which 1.16% was allocated for agricultural irrigation. However, the majority of treated wastewater is still discharged into the sea [65].

While water reuse is an issue of high national priority, several factors are responsible for the limited use of recycled water in Greece to date [65]. The acceptance of the use of recycled water by society is emerging as a critical parameter for the effective implementation of a water reuse system. Numerous international studies have been conducted to examine the factors that influence the greater acceptance of this practice [66]. Most of the research on the acceptance of the use of recycled water in Greece has been conducted in the form of questionnaires or personal interviews, the majority of which has focused on the region of Crete, where the use of recycled water for agricultural irrigation is widespread. Corresponding surveys for other regions of Greece, such as Chalkida, Thessaly, and Thessaloniki, are limited. Respondents included people of different ages, educational levels, social backgrounds, and incomes, and in several cases farmers who had already implemented the use of recycled water in the irrigation of their crops [66].

Based on the results, Greek society adopts a positive attitude towards the use of recycled water for various applications. However, the attitudes of citizens show significant changes when they take into account the origin and possible uses of recycled water. Specifically, the vast majority of respondents stated that they would not choose to use recycled water as drinking water [66]. Its use as irrigation water is more acceptable in crops that undergo some kind of treatment before consumption, such as olive trees, in contrast to vegetable crops, such as tomatoes, which can be consumed without further processing [69]. At the same time, the use of recycled water in activities that are not directly or indirectly related to food (e.g., urban parks, sports fields, firefighting) is more acceptable than all the above applications [65,67,70].

Acceptance of the use of recycled water can be examined from both the perspective of consumers and farmers. From the consumer's perspective, acceptance is affected by environmental awareness, education, income levels, and age. Farmers who face water scarcity problems and apply environmentally friendly practices to cultivate the land are more likely to adopt recycled water for irrigation. Consumers are generally willing to incorporate recycled water into their food purchasing habits, which will also contribute to the wider acceptance of farmers' use of recycled water to irrigate their crops. Thus, a significant change in the social attitude towards the use of recycled water is likely [65,66,69].

The impact of targeted educational and informational programs on increasing public acceptance of the use of recycled water is worth mentioning. Lack of information and education is a proven factor influencing peoples' judgment [67]. The skepticism of consumers, as well as farmers, about water reuse, is mainly due to concerns about health risks. They consider that recycled water can be a source of toxic substances and pathogenic microorganisms and that its use will lead to a deterioration of their health, opinions that are largely attributed to insufficient knowledge and information about the methods of wastewater treatment and water reuse [66,67].

Furthermore, citizens' trust in public authorities plays a major role in the acceptance of recycled water use by people. The overall conclusion is a pervasive doubt about the ability of the authorities to enforce regulations for the welfare of consumers, which further intensifies citizens' skepticism towards water reuse [66,67]. Nevertheless, there is a remarkable social acceptance of the use of recycled water, which encourages the expansion of its applications.

The pricing of recycled water is a special parameter influencing its acceptance by society. The majority of consumers and farmers claim that they are willing to pay a lower price for recycled water than for fresh water. In general, economic factors such as the price of fresh water and income are important in the social acceptance of water reuse [66,69,71]. Particularly encouraging is the research of Petousi et al. [66], from which it appears that a significant percentage of farmers in the region of Hersonissos, Crete, are even willing to invest in new irrigation systems for recycled water.

In summary, despite the challenges, using recycled water is a valuable resource. Greek society demonstrates a positive attitude towards its reuse, mainly in agriculture. The acceptance of using recycled water is multi-factorial. Various surveys reveal diverse views of the community. Citizens express health concerns and doubts about the authorities' ability to enforce the necessary regulations. However, there is a general social acceptance of the use of recycled water, which is enhanced by factors such as environmental awareness and appropriate information. Food producers and consumers are willing to incorporate recycled water into their daily practices and habits, indicating a potential shift in social attitudes, which is believed to be further fueled by citizens' need for fresh water.

8. Conclusions

In this paper, the main goal was to review water reuse through literature on different levels. The reason why water reuse has become so important is none other than the rising water scarcity levels, which are projected to intensify even more shortly. Water withdrawal for agricultural, industrial, and urban use has been one of the main factors that contribute to the water scarcity phenomenon, with agriculture being the main consumer. Industry is also a major consumer and is accompanied by a large production of waste which needs further treatment. The EU has been publishing directives and regulations on water reuse for the last 40 years, the latest being regulation (EU) 2020/741, which sets certain limits connected to minimum requirements for water reuse. The current applications of water reuse in northern Europe are for environmental purposes (51%), while in southern Europe, it is mainly used for irrigation (44%), with Spain reusing the largest volume. However, while a large proportion of urban wastewater is treated appropriately, very little of the treated water is reused due to various barriers that include technical, economic, institutional–regulatory, and social barriers. An extensive review of studies involving the acceptance of water reuse was carried out to identify the reasons why water is not being reused to its full potential. The results varied because of several factors, such as the region, the reuse method (e.g., irrigation, indoor/outdoor activities, drinking water), and due to economic, social, and emotional factors.

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