European Young Engineers

Water Reuse in a Circular Economy

European Young Engineers (EYE)

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European Young Engineers (EYE) is a pan-European non-profit organisation which represents more than 500,000 young engineers from more than 30 professional engineering associations in 25 European countries. EYE has the vision to be the voice of young engineers in Europe and acts as a channel to their opinion towards multiple topics that affect these engineering students and young professionals in their life.

The Public Policy department aims to facilitate this representation process and focuses on some of the overarching themes of the current generation, such as the interface between nature and technology or the future of engineering work.

The EYE's working group 'Water Reuse in a Circular Economy' was established in July 2020. We seek to reinforce the awareness of young professionals and decision-makers on the effects of anthropogenic factors on water resources, and highlight the need to focus on providing opportunities and support to several industries around Europe and the globe.

More than 13 people have been intensively involved in researching, collecting data, and contacting relevant organisations for information for more than 21 months to make the existence of this educational paper possible. The purpose of this educational paper is to raise awareness and provide an insight to industries, engineers, individuals, and possibly governments about how reusing water may be of relevance.

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Content

Introduction

Water: the essence of life. Little needs to be said about the inexpressible significance of water on all levels of existence: from daily individual use to every single drop that once trickled into the soil, now food on our tables, and the massive industrial plants that depend on water to operate. In other words, water is existence and existence is water.

Essential, and available all the time, is it not? It flows from taps whenever we need and streams in our rivers, does it not? In many parts of the world, the answer is no and in regions where the answer is currently yes, the answer could soon turn into a 'no'. Water scarcity sounds like something surreal and yet so real!

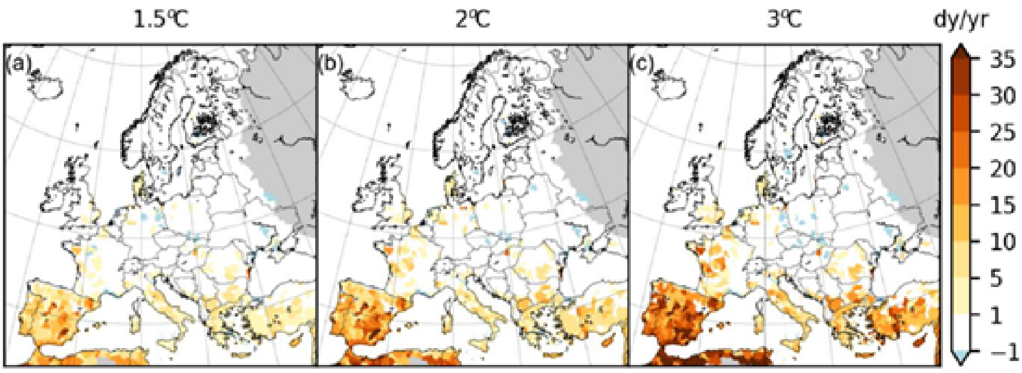


Figure 1. Water scarcity projection based on the ratio between water demand versus total water availability in europe for a global temperature increase of 1.5°C, 2°C and 3°C from left to right [1]

Due to a growing global population, the need for water is expected to further increase. More and more regions in Europe for example – especially in the Mediterranean area – are suffering from effects of droughts caused by climate change. [1]

The warming climate and reduced precipitation in the Mediterranean will cause extreme increases in water scarcity if the water demand stays at the current usage levels, given no significant water-saving efforts. [1]

Using Water Exploitation Index Plus (WEI+) as an indicator for water scarcity (consumption ratio being total water net consumption divided by the freshwater resources of a region), figure 1 shows the projected change in days of water scarcity in a year compared to the present day for a global temperature increase of (a) 1.5°C, (b) 2°C, and (c) 3°C. [1]

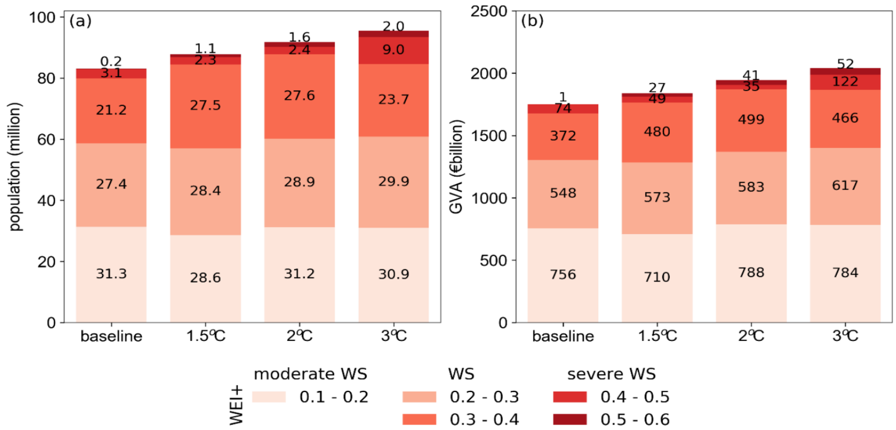


Figure 2. (a) Projected number people and (b) economic activity exposed to different levels of water scarcity (WS) in the EU + UK as a result of climate change for the baseline and for a global temperature increase of 1.5°C, 2°C and 3°C [1]

Furthermore, industries are and will continue to lose money due to water shortages.

In the European Union and the United Kingdom, around 51.9 million people and 995 billion EUR of economic activity are currently exposed to water scarcity (WEI+ > 0.2). 3.3 million people of them and 75 billion EUR economic activity to severe water scarcity (Figure 2). [1]

Even if we manage to pursue efforts to maintain a 1.5°C global warming level, the number of people and value of economic activity exposed to water scarcity could still increase up to 7.4 million (+14%) and 134 billion EUR (+13%) compared to the present climate. Diagram (1.2) illustrates the projected number of (a) people living and (b) economic activity exposed to different gradations of water scarcity (WS) in the EU+UK solely due to climate change for the baseline and under different warming levels. [1]

Globally, climate change including increases in frequency and intensity of extremes have reduced food and water security, hindering efforts to meet Sustainable Development Goals. Although overall agricultural productivity has increased, climate change has slowed this growth over the past 50 years globally, related negative impacts were mainly in mid- and low latitude regions but positive impacts occurred in some high latitude regions. Increasing weather and climate extreme events have exposed millions of people to reduced water security, with the largest impacts observed in many locations and/or communities in Africa, Asia, Central and South America, Small Islands and the Arctic. [76]

Feel with uncertainty and melancholy? So were we. Hence, we at the European Young Engineers decided to step in to contribute in transforming this lose-lose situation into a win-win one, neither by rage nor by blindly screaming on streets, demanding others to take action or proposing impractical solutions, but by taking as many factors into account as possible, trying to inspect and evaluate different aspects that concern reusing water, deepening our understanding of this crucial topic.

In line with the United Nations' Sustainable Development Goals and as water scarcity, climate change, and lean, circular economies are increasingly gaining interest, we strive to shed light on creative solutions available that will promote sustainable use and reuse of water resources in European industries, introducing some available and potential technologies, in addition to the fundings available. Vital mechanical, chemical, and biological methods are compared, in addition to introducing the idea of artificial intelligence (AI) in water reuse.

Now, are economic factors the only driving force for reusing water? No! Therefore, we also focus on the legal aspects, both barriers and opportunities, in addition to how industries may consider reusing water, not only to their benefit but also to that of the environment and the community or communities they operate in. The ecological impact is included as well, in addition to the social dimension of reusing water.

In January 2021, a webinar was organised on the topic with industry experts, including the European Commissioner of Environment, Oceans, and Fisheries. The link to the webinar can be found here: https://eyengineers.eu/webinar-water-reuse-for-a-sustainable-industry/

For questions, remarks, or suggestions, the working group can be contacted by email: Amir Dastgheibifard (Working Group Leader) amir.dastgheibifard@eyengineers.eu or water-reuse@eyengineers.eu

The Social Dimension of Water Reuse

What does Social Sustainability mean? The United Nations defines it as identifying and managing positive and negative impacts on people. Some recognized social issues include human rights, labour, gender equality, children, indigenous people, and education [5].

Particularly to water reuse, the European Commission identifies several positive social impacts such as food and economic security, employment benefits, and overall greater quality of life. That can be translated into a greater and more reliable availability of water and its supply, allowing to maintain attractive landscapes and securing rural businesses [3].

The Sustainable Development Goals developed by the United Nations call for action regarding water reuse, as it is directly referred to in the 6th SDG. It calls for clean water and sanitation for all people, meanwhile ensuring its availability for everyone and being managed from a sustainable perspective [4].

Additionally, water reuse can also have an impact and contribute to SDGs 1, 2, 3, 8, 11, and 12. For example, by creating and securing jobs, securing access to clean water, or leading to a higher life quality [4],[27].

In addition to data from international associations and governments, it is also acknowledged by academic books and peer-reviewed journal articles that the reuse of water creates potential for new sources of clean water, improves sanitation, and diversifies the water resources available with special value during droughts when surface and groundwater are more limited for all of us. This, in turn, could give a sense of security to the societies [4].

Altogether, it is recognized that water reuse requires robust regulations, advanced technology, and political support. Similarly, water reuse raises health and environmental concerns, knowledge gaps regarding the mixture of contaminants, technical barriers, and finally managerial and financial concerns regarding the viability of water reuse schemes [4].

Regarding potable water reuse, it can be categorised into two types. Firstly, indirect potable reuse, which uses an environmental buffer, such as a lake, river, or groundwater aquifer, before the water is treated at a drinking water treatment plant. The second type is direct potable reuse, which involves the treatment and distribution of water without an environmental buffer [6].

The use of such water as a drinking source raises psychological barriers [4]. It is not a common practice largely because many people are repelled by the thought of drinking water that has been once in toilets. Other barriers can relate to health, education level, religion, development of the state of the society, the extent of public participation, and importantly, communication [2].

Some prominent figures, like Bill Gates, have tried to break this barrier but it is certain that for a prevalent acceptance, huge socio-educational campaigns need to be initiated (Figure 3). That can, however, only be successful if there are standards set for the quality of the water to be reused along with logical policies that can be practically executed on a large scale, bringing us to the next topic.

Figure 3. Bill Gates drinks water from the "Omniprocessor", a machine designed by Janicki Bioenergy that turns domestic wastewater into potable water and electricity.

European Commission Policy: Water reuse regulations and the Circular Economy Action Plan

Water reuse is deployed below its potential in the European Union. Reuse of appropriately treated wastewater, for example from urban wastewater treatment plants or industrial installations, is considered to have a lower environmental impact than other alternative water supply methods, such as water transfers or desalination, but such reuse only occurs to a limited extent in the Union. This appears to be partly due to the lack of common Union environmental or health standards for water reuse [7]. Limited awareness of potential benefits among stakeholders, the general public, and the lack of a supportive and coherent framework for water reuse were identified as two other major barriers preventing a wider spreading of this practice in the Union [9].

In 2018, the Commission proposed a regulation formed by: water reuse minimum requirements of treated urban wastewater [9] and an impact assessment. It was performed by several European committees and based on supporting policies, studies and stakeholder consultations. It aimed to assess the options of water reuse in agricultural irrigation and aquifer recharge and it resulted in the development of policies and a set of minimum quality requirements [7].

Worthy of mentioning is that there cannot be a single standard set for all sectors. Different sectors require different levels of water quality, as far as water reuse is concerned. For policy makers and governments, comprehension of the above is critical. Furthermore, the best policies would be those that take all possibilities and barriers into consideration, ensuring a win-win situation for almost all stakeholders if the respective policy is to succeed.

In June 2023, the European Union will apply new regulations on minimum requirements for water reuse in agricultural irrigation. For example, by setting out minimum requirements for treated urban wastewaters and additionally monitoring and validating them. Other displayed regulations will relate to the assessment and response of potential health and environmental risks, permitting requirements, and public transparency of any water reuse project [9].

The Circular Economy Action Plan will provide a future-oriented agenda to accelerate the transformational change required by the European Green Deal while building on circular economy actions [8].

Particular to water reuse, it will encourage and facilitate circular approaches in agriculture and industrial processes in addition to adding legislative requirements for water reuse [9]. Furthermore, a management plan of sustainable applications on nutrients will be developed [8].

Just like the regulatory, economical factors are of utmost importance, so are the ecological impacts of reusing water.

The Ecological Impact of Water Reuse

In general, wastewater reuse has been considered an additional source for arid or semi-arid areas. However, considering a broader context where environmental impacts have important implications for water supply, the analysis must be broadened to encompass benefits other than economical ones. Wastewater treatment is seen as a production process that gives rise to both desirable clean water and a decrease in pollutants [10]. Water reuse aims at a series of environmental benefits that tend to make it acceptable and desirable[11]. The question is: what are those?

To begin with, recycled water is mainly used to supply non-potable water demands, and it is especially useful when it comes to injecting water to recharge groundwater aquifers and reservoirs. In terms of water reuse, this extra water represents a huge relief to water bodies found in every ecosystem. In other words, reusing water reduces the need for drinking water being used for non-drinking purposes.

Figure 4. Water Reuse prevents saltwater intrusion in groundwater in coastal areas as a result of either sea level rise or overdrawing.

Additionally, injecting reused water is an important way to prevent saltwater intrusion, especially in coastal areas commonly affected by the detrimental effects that high salinity is known to have in soils (figure 4) [12]. An example? Orange County, California, has been pumping highly treated recycled water into the aquifer to prevent saltwater intrusion while augmenting the potable groundwater supply [13].

Talking about salinity, reusing wastewater could significantly lessen the demand for the costly, highly energy-consuming desalination facilities in relatively arid regions, dramatically and directly plummeting the 'sea' of environmental and economic disadvantages that the process of desalination causes. These include but are not limited to: Emission of greenhouse gases that are usually caused by electricity generation and endangering sea life. For comparison, desalination could use up to 200 million kilowatt-hours to produce one cubic metre of freshwater from seawater each day, whereas a traditional drinking water treatment plant typically uses well under 1 kWh per cubic metre. [11], [19]

In some places where both humans and wildlife rely on groundwater sources of freshwater, urban water reuse can hence contribute in three ways to improve the issue of reduced groundwater quality or availability:

- Indirectly, by substituting groundwater as a supply source and thereby avoiding extraction, thus increasing the recharge/withdrawal ratio,
- Directly, by substituting water for irrigation with less saline water.
- By managed aquifer recharge. [12]

There are more benefits.

Several plants, wildlife, and fish that depend on sufficient water flow in their habitats to live, survive, and reproduce would have an adequate water supply. In other words, 'reuse is reproducing', especially when it comes to augmenting water supply crucial to sustaining aquatic and wildlife habitats with streams that have been impaired or dried [13].

In simple terms, through water reuse, the freshwater volume that is removed from surface bodies is reduced, as well as the discharged pollutant load, which protects and improves the water quality. Therefore, the primary benefit of water reuse is water conservation via the substitution of natural water resources with treated wastewater [14], [15]. It helps to decrease the diversion of water from sensitive ecosystems and bodies of water due to wastewater streams from agricultural, urban, and industrial use. These wastewater streams can be reduced when they are treated and reused, thereby, the pollutant loadings in the ocean and rivers can be decreased and prevented [13]. Recycled water is a valuable resource. Instead of being thrown away, appropriately treated water can be recycled – used a second time – to reduce the demand on high quality freshwater sources and improve environmental water quality [18].

If it is all easy and good, then why did not we come up with this earlier?

Well, it is not that simple. Some challenges need to be taken into account. According to the World Health Organisation (WHO), there are significant health implications associated with the use of sewage for irrigation. These “sewage chemicals'' contain domestic, industrial, pharmaceutical, and hospital waste discharges. The following chemicals may typically be found: salts, minerals, heavy metals, pesticide residues, and synthetic compounds such as disinfection by-products, pharmaceutically active chemicals such as endocrine disruptors, and various acids. Some chemicals, for example, bromodichloromethane, may be associated with miscarriages in women, while heavy metals may accumulate in the leaves or roots of many vegetables, posing risks to human health when consumed. [20]

It is of utmost significance, therefore, that if water is to be reused, it should be adequately treated for the respective purpose. Here is where engineers can sparkle some magic and develop procedures that treat water adequately for different purposes cheaply and efficiently.

Furthermore, sewage effluent (especially when inadequately treated) also contains high levels of microorganisms such as bacteria, viruses, and parasites, of which the majority may pose a serious health threat after exposure/ingestion. [20]

However, greywater can be reused for landscape irrigation in surrounding agricultural areas, acting as natural fertiliser in grasslands and other ecosystems because of its higher levels of nutrients, such as nitrogen and potassium, hence being advantageous for wildlife and farmers by reducing the need for artificial/chemical fertilisers. In conjunction, treating wastewater helps to save water for both humans and ecosystems. The latter is critically important for ecosystems that suffer from long-term drought conditions, considering that recycled water saves freshwater. Similarly, this reuse improves water quality and prevents flood diminishment in wetlands. That said, recycled water may also help to create new wetlands and riparian habitats [13]. The use of reclaimed water for agricultural irrigation of non-food crops or for food crops intended for human consumption that will be commercially processed presents a reduced opportunity of human exposure to the water, resulting in less stringent treatment and water quality requirements than other forms of reuse. [17]

To summarise, utilisation of treated wastewater results in substantial benefits when it comes to protecting aquatic species, terrestrial animals, or conserving freshwater ecosystems [11]. All advantages, that could heavily outweigh the minimal downsides of reusing water if the challenges are to be considered and dealt with realistically. New scientific breakthroughs will lead to enhanced understanding of the significance of criteria found in both water and wastewater and their significance to human health. New regulations will be needed to reflect this enhanced biological and chemical understanding. [16]

What a better way to end an educational section than with a poem originally from Nancy Willard, but greatly modified for this article's purposes:

"Ah, People, we're weary of wastage",

said the water droplets, shining, as they form a dew.

"Your blind consumption habits have tired us.

Is reusing such a difficult idea to see-through?"

The Industrial Aspect of Water Reuse

Nowadays industries are facing the challenge of increasing productivity and at the same time reducing their environmental footprints. Concerning water consumption, reducing environmental footprint means reducing consumption, enhancing treatment efficiencies, reducing wastewater and boosting reuse [22].

Generally, industrial water use has a wide range of applications and different requirements regarding its water purity. For reusing water that is tagged as waste, it needs to be treated to fulfil the purity standards that are set by the EU. Those treatment methods are for example:

- <u>Mechanical treatment, or the separation of particulates.</u> There are two main factors: length and density. The most common methods are sedimentation, straining and flotation. Regardless of which method is used, all of them aim to determine the form in which pollutants are present in the water. From a physical point of view, the pollutants can be divided into particles and dissolved substances.
- <u>Biological treatment</u>. The most important process is aerobic (microorganisms need access to oxygen) biodegradation and it is used in both municipal and industrial waste water treatment plants. That process degrades organic compounds to carbon dioxide, water, and cell mass. Another process is anaerobic biodegradation (degradation occurs in the absence of oxygen) of organic carbon compounds into biogas, water and cell mass. The biogas can be purified in a biorefinery into carbon dioxide and methane; the former can be used as raw material in the food industry in the production of carbonated beverages, and in the chemical industry specially in urea manufacturing; and the latter is an alternative source of energy. Moreover, anaerobic biodegradation is a key step in a biorefinery, a structure in which biomass (waste organic matter with high content of cellulose and hemicellulose) is an optimal and sustainable manner to produce different value added products that tries to be self-sustaining. [77] That is, a biorefinery is a promising concept in which multiple manufacturing processes are connected in a circular economy, and where all their waste is utilised for a wide-ranging product portfolio to satisfy the different needs of society. [78] Finally, two other processes to be named are nitrification and denitrification, used to reduce the nitrogen loads in water.

- Chemical treatment. It is a common process in a water treatment context. Regarding industrial waste, the process of chemical precipitation is mostly used for metals, therefore it is relevant to industries such as iron and steel. On the other hand, during the treatment of municipal waters, chemical precipitation is used for phosphorus reduction. Other relevant processes for industrial use include chemical flocculation, used for flocculation of fibres in waste waters such as the pulp industry or neutralisation, a process which neutralises acidic solutions by using a sedimentary rock such as limestone [63].

The use of treated wastewater from municipal or industrial treatment plants as clean water can be associated with a wide range of problems. Due to variations in the water volumes entering the treatment plant, it may be hard to guarantee that the standard of the treated water meets the quality level required. The appearance of disruptions or breakdowns is one of the complications [63]. This hints at the idea that we might want to rethink our current water treatment facilities and re-engineer them to make them viable for future tasks. An established measure to procure them is the reuse of water for purposes with lower quality demands, called the down-grading of water.

Finally, another identified problem is the accumulation of hazardous levels of pollution in the treatment plant. Some technologies to solve such circumstances are costly and include ultra-filtration and reverse osmosis [63].

In entire Europe, water reuse does not stand out, as it is calculated that less than 3% of urban wastewater is reused [64]. However, outside Europe's frontiers, numerous applications on water reuse can be highlighted.

Firstly, reused water can be used as drinking water, and the following cases can help to illustrate it:

- In Singapore they use an innovative NEWater Technology three stages process. The first stage is known as microfiltration/ultrafiltration and it passes treated used water through membranes in order to filter out particulate matter and bacteria. By using a membrane with very small pores, other contaminants such as viruses are absorbed via reverse osmosis. Finally, the third stage verifies through ultraviolet disinfection that all bacteria and viruses are gone and guarantees the purity of NEWater. The success of such technology can be attributed to financial and political arguments [65].

- Namibia uses a similar technology called "multi-barrier" technology, composed of ozone treatment, ultra-membrane filtration and residual chlorination [66].
- In the United States, some states such as California, Virginia, and New Mexico also treat water and use it for drinking purposes. Some of the technologies used include ultrafiltration, reverse osmosis, and ultraviolet advanced oxidation processes. Waste water going through such processes results in drinking recycled water, demonstrating that purified wastewater can be safe and clean, and help ease water shortages [68].
- Another example is found in the United States, the GWRS. It is the world's largest water purification system for indirect potable reuse. The system takes highly treated wastewater that would have previously been discharged into the Pacific Ocean and purifies it using a three-step advanced treatment process consisting of microfiltration, reverse osmosis, and ultraviolet light with hydrogen peroxide [67], [69].

Secondly, water reuse can be also specific to non-potable purposes. A great example is the Sulaibiya facility near Kuwait City, Kuwait. It is the world's largest membrane-based water reclamation facility. The Sulaibiya facility is used for non-potable uses that impact the drinking water supply by blending it with brackish water to better exploit existing brackish water distribution facilities. - pre-filtered with disc filters and then fed to the ultrafiltration (UF) system – then osmosed [70].

Similar to wastewater treatment, the reduction of water consumption is an established industrial handling-process-internal measure. The different possibilities to reduce water consumption can be divided into a hierarchy of measures according to the following, the simplest and therefore also the cheapest being given first [63].

1. Reduction in the uncontrolled/completely unnecessary water use
2. Measures for improved control of existing water system
3. Reuse of water without treatment where possible (down-grading)
4. Recycling of water in the process after process-internal or external treatment
5. Change the process design so that no water/little water is needed

A third industrial wastewater internal measure is wastewater separation. By separation, it is meant to isolate the different types of used water (process wastewater, cooling water, sanitary wastewater, and stormwater). If different types of wastewaters are handled separately, the volume of wastewater that requires extensive treatment can be reduced considerably. In this way, it is possible to target the most polluted wastewater for extensive treatment, while less polluted water streams undergo less thorough treatment [63].

After describing a series of industrial water reuse aspects, it is time to explore how some of these aspects and measures are applied best in various manufacturing industries around the world.

Electricity generation, distribution, and cooling accounts for the largest share of total water consumption in the European Union, followed by the manufacturing of refined petroleum products and chemicals. The latter is considered to generate the highest share of wastewater [26].

The chemical water industry-main applications are heat exchange, use as a solvent, or as carrier media. During the process, a part of the water evaporates, and another becomes part of the final product. Nevertheless, the highest percentage is waste and polluted water [72]. In that event, academic research within the industry does not seem to reverse the situation as its main aim is to reduce freshwater consumption [24].

It is also remarkable to note that the steel industry and coal-based chemical industries are two of the largest water-intensive industry processes. The academics within these industries aspire to improve its water usage by reducing its freshwater consumption and discharges to the environment. [24]

Industries with inferior water use but still significant shares include for example the textile industry, which sets objectives to minimise total freshwater use, wastewater reduction or to set up wastewater treatment systems. Other examples include food products such as milk or yeast industry and pulp and paper, all aiming to minimise fresh water consumption and wastewater generation. [24]

Industrial wastewater cannot only be reused in the industry but also plays a big role in irrigation [28]. In fact, agricultural water reuse is the leading application of treated wastewater globally. However, a proper water treatment system needs to be in place as it might lead to potential health risks. It is noted that approximately 91% of the recycled water used for the agricultural industry is assigned for crops and pasture irrigation. Among many, the production of fruit, nuts, vegetables, and grain [23].

The leader in water reuse in arid climates is by far Israel that has been using recycled water for agricultural irrigation since the 1970s. Today, Israel recycles 90% of its wastewater. A staggering 85% of this water is used in agriculture each year [71].

The importance of setting minimum requirements of water reuse within the European Union is discussed by the academics. In that manner, it might create a broader uptake of water reuse. For that to happen, great knowledge on water reuse and financial investments are remarked as requirements. Such a scenario is plausible by considering the concept of industrial symbiosis, particularly concerning by-products reuse.

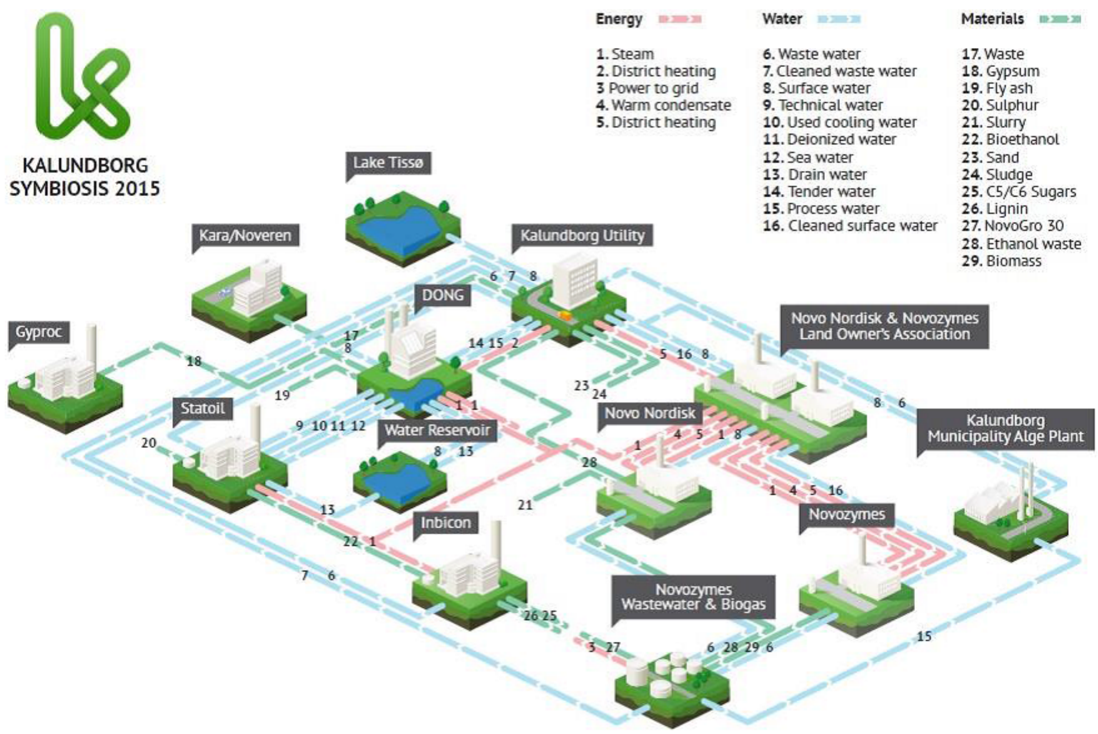


Figure 5. Kalundborg, Denmark, an inspirational example of Industrial Symbiosis in a Circular Economy where the by-product of one company is the raw material for the industrial process of the another company.

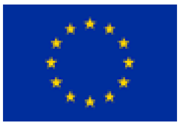
This concept can also be also defined as "the activity that engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products". This idea executed by The Kalundborg Utility in Denmark can be broken down in simple terms: the residues of one company become resources for another company, including wastewater which is exhaustively treated and then recirculated at least 3 or 4 times. [41],[42] The utility has one of Europe's most advanced wastewater treatment plants whose only by-product is sand and sludge. In this site, different manufacturing companies are physically connected through 22 streams in a closed-cycle pipe system which facilitates the reuse of water for cooling and heating purposes, and for biogas and electricity production, among others (See fig 5). In line with this, there are several financial and environmental benefits; The Kalundborg Utility with more than 12 companies is currently saving USD 28 millions and 700000 Tons of CO_2 per year, with support of. [41], [43]

There is no doubt that trust and modifications of current practices are required both for direct reuse and treat-and-reuse of water between industries [73]. This symbiosis center is an inspiration towards zero waste keeping low prices and high quality and security of water supply. Moreover, a potential commercial exploitation of industrial process water and CO_2 are among the future promising perspectives that includes the microalgae industry. Microalgae can grow while removing phosphorus and other nutrients that remain in wastewater from different industries and its production will help to create higher value biocomponents such as plant protein, plant lipids, and biopigments [25].

To summarise, industrial wastewater from numerous industries on a global level has the capability to cause irreversible problems to the environment and human beings, but with adequate treatment and recycling methods being introduced, they can play a positive role and be economically useful [21]. A central issue could be funding such ideas, which brings attention to the next topic.

Funding Water Reuse

Many of the water reuse projects, from research to execution, require funding. The lack of funding or insufficient funds could be the main barrier to the execution of water reuse projects. Therefore, there are many ways in which projects can be supported financially. Especially the European Union, but also other institutions, can be a helping hand when it comes to developing future water treatment plans.



The European Union strongly believes in national and international investment in water research and innovation between the public and private actors in order to overcome world water supply challenges. These challenges are set to become even bigger in the future: climate change, increasing demand, and contamination of groundwater, and scarcity due to changing diets will have an increasing impact over the next decades. A boost in funding for water reuse projects that would help improve governance, regulation, public perception, water resources planning, and other aspects of water policy that also present a significant challenge to water reuse [29],[30].

The European Union is adopting innovative solutions to tackle water quality and quantity issues, alongside water management and governance, including circular use of water and research on the optimization of water use as well as the efficiency of water recycling [29].

Funding Opportunities provided by the EU:

- **Horizon Europe**: This is an initiative aimed at securing Europe's global competitiveness and economic growth. Moreover, it is intended to make sure different projects achieve results faster and get off the ground with ease while acting under "Access to Risk Finance", and creating jobs based on excellent science, industrial leadership, and tackling societal challenges by coupling research and innovation. For instance, Horizon had the biggest EU Research and Innovation program ever with nearly €80 billion (The percentage of investments on water innovation or water supply was, however not mentioned) of funding available over seven years (2014 to 2020) [31], [32].

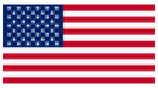
Furthermore, the European Commission presented a new Circular Economy Package to have a greater impact on recycling and reuse, bringing benefits to both the economy and the environment. A series of actions on water reuse, such as a legislative proposal for the reuse of wastewater, was included, among other key actions. Moreover, Horizon 2020 had a Funding of over €650 million that benefited several projects, one of them related to "nanofiltration with membranes for the application in water treatment and process technology" and "WaterWorks2014" that aimed at tackling European water challenges [33].

Additionally, Horizon for 2021 – 2027 has a budget of €95.5 billion, with mission areas such as adaptation to climate change and healthy oceans created to help achieve the UN's Sustainable Development Goals, and help towards Europe's plans to transform science leadership into global leadership in entrepreneurship and innovation by 2027 [74], [75]. The pillar II of Horizon contains a budget of over €15 billion for climate and energy and funding of €9 billion for bio-economy and natural resources, which can benefit water reuse in the EU along with other closely related aspects. However, this funding is not exclusive for water reuse projects. [74], [75] Other financial support mechanisms of the EU include loans and grants, including the LIFE+ Climate Action and the Recovery and Resilience facility. Programs like SUWANU Europe and the JPI (Joint Programming Initiative) also have a history of providing funds for water projects. Both projects are intended to promote water reuse in agriculture, and help to address the diverse challenges in agriculture, food security and climate change. [34], [36]

- **European Investment Bank (EIB)**: The EIB is one of the largest lenders to the global water sector with €79 billion funding available for over 1600 projects in regard to water security [35].

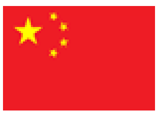
Outside the EU

Disclaimer: This list is not exhaustive and fundings may be available that do not directly relate to water reuse, but may provide financial assistance when it comes to projects of water reuse. It is recommended to do further research to find out possible further fundings available in your local community.



The U.S. Environmental Protection Agency's (EPA) Clean Water State Revolving Fund (CWSRF) program is the largest public source of water quality financing in the United States. CWSRF programs could be compared to "banks", providing several types of funds for a wide range of water infrastructure projects. Eleven types of projects are eligible to receive CWSRF assistance, including water reuse projects [37]. In addition, there are fundings provided individually by some states. Associations, like 'WateReuse', are dedicated to advancing laws, policy, funding, and public acceptance of recycled water as well [38]. Similarly, as of 2020, several water reuse projects of the Water Recycling Funding Program (WRFP) in California received more than USD$221 million in grants and almost USD $900 million in loans [39].

The Canadian Government's CWWF (Clean Water and Wastewater Fund Program) provides short-term funding of $2 billion. The CWWF will be largely managed through funding agreements between the Government and each province and territory, which will be responsible for the administration of the programs and may further distribute funds to the eligible recipients for eligible projects. [40]



Since 2013, China has been making an effort to reuse even more water, creating incentives such as tax deductions for companies that invest in water recycling technologies [44]. The China Water Affairs Green Finance Framework is offering green bonds, loans and the use of proceeds to finance future projects. The projects are eligible as long as they belong to one of the following categories: Sustainable Water, Wastewater Management and Renewable Energy. The amount of funding available, however, is not specified [46], [47]. It is anticipated that, by 2025, more funding will be available towards projects that help to achieve a systematic and efficient pattern of wastewater resource utilisation in domestic, industrial, and agricultural applications [45].

The Israel-Sweden collaboration (as a part of the Jewish National Fund) will support eight projects focused on Water Management and Energy Generation with total funding of USD $70000, where different researchers in the academy and industry are eligible [48]. Furthermore, the Israel-Argentina cooperation between the Ministry of Science, Technology, and Innovation of the Argentine Republic and the Ministry of Innovation, Science and Technology of the State of Israel, will provide USD $20000 of funding for five projects in science and technology during two years, where some of the subtopics are climate change and water management. All researchers and scientists are invited to submit joint proposals for research projects carried out by scientists from both countries [49]. Another example is the Wohl Alliance which is an initiative of the British Council, together with the U.K. Science and Innovation Network, and the Israeli Ministry of Science and Technology. The latter collaboration has grants of up to USD $25,000, and aims to further research in areas of clean growth of food and water management. Currently, proposals can be submitted at any time; however, only U.K. or Israeli universities and academic/research institutions can receive the grant directly [50].

The Australian Government has opened applications for $72 million of water infrastructure funding. Even though the percentage of investments in wastewater treatment and reuse is not mentioned. Examples of eligible projects include dams, water supply pipelines, groundwater, and managed aquifer recharge supply schemes, and water treatment infrastructure, including desalination technology and wastewater treatment plants. Only territory governments are eligible to apply for the funding, but they can partner with local Government and/or private organisations on the projects [51], [52]. Furthermore, The Australian Water Recycling Centre often offers more than $20,000,000 fund for projects aiming to enhance the efficiency, expansion and acceptance of water recycling, including innovative technologies [53], [54], [55]. The funding is distributed among the Government, academia, and private enterprise sectors.

Singapore's Public Utility Board (PUB) is offering a funding opportunity of up to USD$19 million for water-intensive companies over the next three years. That is, companies with more than 60,000 cubic metres of consumption per year could reduce their consumption by up to 70 percent through water recycling. These companies are allowed to tap on funding following one of the three schemes: Water Efficiency

Fund, Industrial Water Solutions Demonstration Fund, or Living Lab (Water) Fund. PUB is aiming to save 10 million gallons per day (equivalent to around 37.58 million litres per day) of water in the next year and is considering up to 34 projects to achieve this goal. Projects whose main area of focus are reducing energy use in seawater desalination, increasing energy self-sufficiency in wastewater treatment, and reducing industrial water demands are also eligible [56], [57].

Digitalization and Artificial intelligence in Water Reuse

The 21st century is deemed to be the era of digitalization, automation, and Artificial Intelligence (AI). The long-term vision is to live in an environment that works with maximum efficiency. That principle could fit almost every aspect of society, like transportation, energy harvesting, or water management.

Critics of digitalization often refer to the high cost of implementation, the high energy consumption, and safety issues of complex systems that are not only able to monitor, but also to intervene in processes. It needs to be kept in mind that digitalization is a system that sometimes does complement other previous solutions but very often also replaces old technology. In the end, society must value their resources in the future the best it can do, to keep the quality of life, or does anybody think that the current consumption of resources is at a healthy level?

This does especially connect to the way how the water situation is managed in Europe, no matter if the freshwater consumption or the recycling of greywater in processing plants is focused on. When talking about Artificial Intelligence in the Water Industry experts did elaborate three main goals:

1. The processing of used water is a very cost-intensive process. Making the process more efficient has the potential to lower the cost significantly.
2. The second goal is to classify the used water by AI. In recycling, it is crucial to identify the substances that contaminate the water. Different ways of recycling or processes are suited for different contaminants. For an ideal way to restore the used water, AI can help identify the best ways to do the treatment process.
3. Finally, the third goal is to develop a more efficient system to distribute water. There are many ways where the flow of water can be used more efficiently by using improved sewer systems. Water must be seen as an important resource, that is too precious to get wasted. Using AI to navigate water flow through sewers has the potential to use water more than one time before it gets labelled as greywater. Water that is passively

used by the industry, like for cooling, does not have to be drinking water quality. [58], [59]

There are some examples in the scientific community that prove the importance of the issue in a very obvious way. Scientists from the South China University of Technology researched a system that is built to predict the COD load in municipal sewage. The COD is the chemical oxygen demand and is a parameter that indicates how much the water is contaminated with pollutants. The goal of this operation is to make the process of cleaning the wastewater more efficient and therefore cheaper and more feasible. The outcome was that with only four input parameters a prediction accuracy of nearly 99 % was reached. That shows the potential of AI. [60]

Another study was conducted at the Wayne State University that also dealt with the aeration process at wastewater treatment facilities. That process is a complex dynamic task that is important in terms of water quality and energy consumption. That is why the researchers developed dynamic control processes with the help of AI to save energy and costs. The outcome was a reduction of energy consumption by 31.4% due to aeration oxygen reduction while maintaining the same effluent quality, considering 35 different parameters. The amount of saved energy is astonishing even when considering the complex input system they have built. [61]

Energy saved = a lot of money saved as well and that is particularly important for organisations concerned with maintaining market competitiveness.

Both examples show that connecting AI can be a big part of the future of organising water management as well as other parts of the industry. However, there are some concerns connected to Artificial Intelligence. The biggest concern of them all is probably safety and privacy. Especially when talking about a vital resource to every human, safety is the most important aspect. There are many reasons why an AI system can fail. From programming bugs that can occur a long time after a system is launched to attacks from external agents. Total privacy with a system that needs to communicate with different points of infrastructure is nearly impossible to manufacture. [62]

Although the concerns of the biggest visionaries have put their hopes in the future of AI when it comes to a sustainable future. The logical conclusion could be to intensify the effort to build up smart infrastructure.

"I imagine a world in which AI is going to make us work more productively, live longer, and have cleaner energy." - Fei-Fei Li, Professor of Computer Science at Stanford University

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