Water stewardship:
Trends and perspectives within the global process industries

Contents

1. Introduction

Water[1] is a critical resource for almost all types of process industry. Failure to ensure water supply, whether in terms of quality or quantity, may lead to significant production losses. Failure to maintain wastewater treatment can have a devastating impact on the local aquatic environment.

Water plays an essential role in both the manufacturing process, cooling, heating, and not least, cleaning. As global water scarcity and environmental concerns mount, the industry faces transformative changes driven by sustainability and efficiency imperatives. Most water consuming industries also produce vast amounts of wastewater, which requires treatment before discharge into the water environment.

In this paper, we will look at the different global trends, provide statistics on some of the largest water consuming industries and describe the main risks and some of the most frequently used solutions within water management today.

1.1. Water's importance to the industry – Materiality assessment for water

Water plays an essential role in the manufacturing process, including products, prioritising cleaning of process equipment, packaging materials and utilities. As global water scarcity and environmental concerns mount, the industry faces transformative changes driven by sustainability, legislation and cost imperatives.

For the brewery and soft drink industry, for example, water is the most significant raw material ingredient in the finished product. This means that water constitutes a very significant operating cost for the brewery sector, regardless of whether it is supplied from municipal utilities, surface water intakes or from owned groundwater. Breweries are a significant consumer of water and have a large impact on total water use in local communities.

Access to water is crucial for both business success and the environment. For the brewing and soft drink industries, water is the most significant raw material ingredient, constituting a major risk for business continuity.

Likewise, the dairy sector relies heavily on clean water for hygienic cleaning with many dairies adopting innovative water recycling strategies.

Dairies are often located relatively close to the agricultural production areas and in many cases have their own water supply. Optimizing Cleaning in Place (CIP) water, general reuse of water and not least reuse of Condensate of Whey Water (COW)[2] is a general trend for most dairies around the world.

In the life sciences industry, water is heavily depended upon the good manufacturing process (GMP) requirement, but more and more companies are looking into new and water reduction processes and technologies.

The majority of global life science production is based in developed regions such as North America, Europe and parts of Asia (like Japan and South Korea). Developing countries account for a smaller share, however, the market in developing countries is gradually increasing and these countries invest more in healthcare infrastructure, research and development, and education, thereby implying increased local life science production.

Within recent years, we clearly see that many life science industries are prioritizing the importance of water more and large life science corporations no longer take the availability of vast, available water resources for granted. In addition, regulatory requirements for wastewater discharge seem to play a larger importance than water supply risks. Compared to the final product value, the water supply, water treatment, wastewater treatment and wastewater discharge also often totally comprise a smaller operating cost component compared to labour costs, energy and R&D.

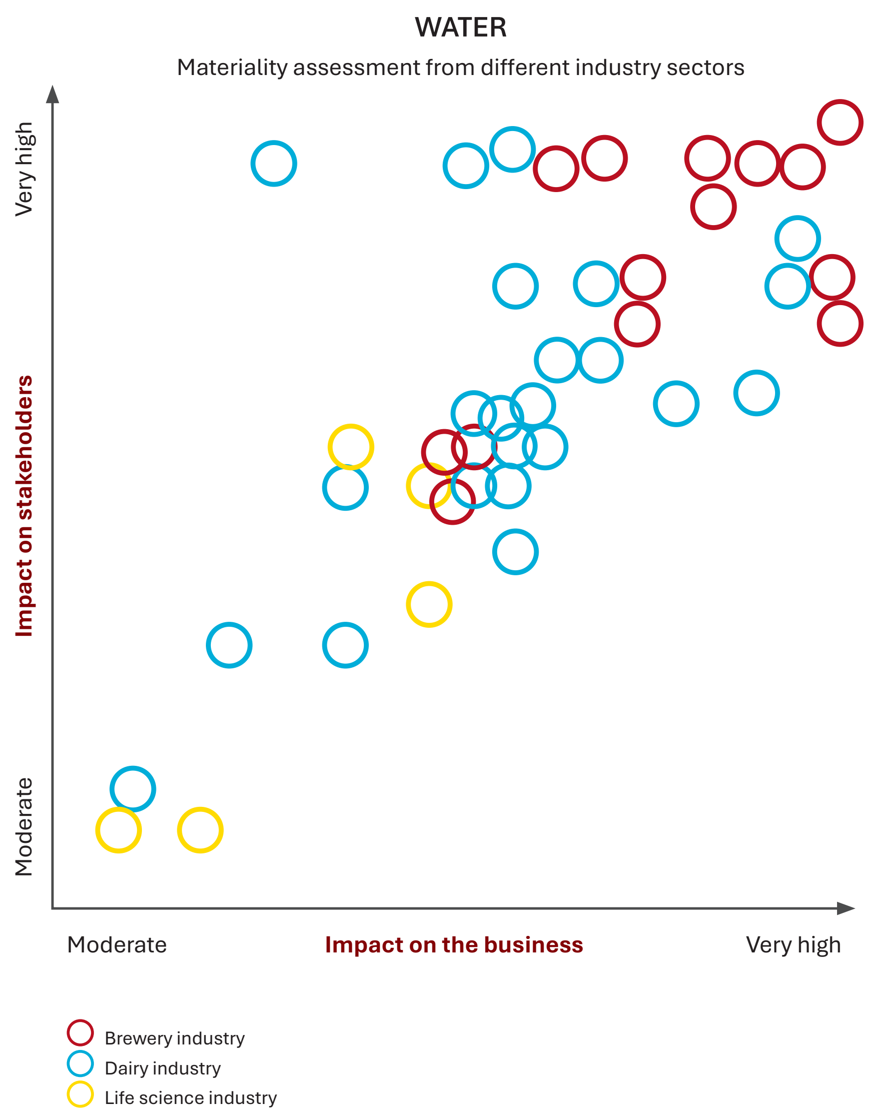


Figure 1 Materiality assessment retrieved from 43 large brewery, dairy and life science industries[3]

2. Global water trends in the process industries

With the pressing need to conserve water, the process industry is increasingly adopting sustainable water management practices. These include reducing, reusing, recycling and rethinking water. Wastewater is now often treated and repurposed within the same facility, significantly reducing freshwater consumption. Advanced treatment technologies such as ultra-filtration, reverse osmosis, and ultraviolet disinfection are employed to ensure water quality and safety. These technologies are also utilised to help companies work towards Zero Liquid Discharge (ZLD).

Innovations in water-efficient technologies are gaining a lot of traction globally. The integration of Cleaning In Place (CIP) and closed-loop cooling and heating systems minimises water loss by recirculating water within the processes. Additionally, smart water management systems equipped with sensors and real-time monitoring can enable substantial savings through precise control and optimisation of water use and quality control.

Governments and regulatory bodies worldwide are tightening regulations on industrial water usage and discharge, and require compliance with international benchmarks such as EU Best Available Technology Reference Documents (BAT / BREF). In addition, a lot of the process industry is forced to adhere to stringent standards for water quality and pollution control. Consequently, there is an increasing emphasis on transparent reporting and compliance with environmental norms, driving companies to adopt best practices in water stewardship.

The world is facing the consequences of climate change. For industries, climate change poses significant risks related to water availability, water quality and flooding. Hence, the process industries are compelled to adapt climate mitigation measures by incorporating resilience strategies, such as investing in infrastructure that can withstand extreme weather events and fluctuating water supplies. Companies are more frequently exploring alternative water sources, including desalination, rainwater harvesting and managed aquifer recharge, to mitigate the impacts of water scarcity and set up emergency plans for water supply failure.

Addressing global water challenges requires collaborative efforts across industries, governments and communities. Public-private partnerships and industry alliances are being formed to share knowledge, resources and technologies that promote sustainable water use. Such collaborations are crucial in developing scalable and innovative solutions to ensure a sustainable water future for the process industry.

Large global breweries saved more than 6% water in one year

Around 85% of the world's largest breweries highlight efficiency initiatives focused on water. Most of the largest brewing corporations have also joined programmes such as CEO Water Mandate, Beverage Industry Environmental Roundtable (BIER) and Water Stewardship or work proactively towards sustainable water use.

19 of the world's 40 largest breweries were found to report their annual water consumption by volume. Together 50% of the largest global breweries consume more than 500 million m^3 freshwater annually. Water savings are in focus by most large brewery corporations and compared to recent years the reviewed brewery corporations have reduced their water consumption by more than 6%.

More than 2/3 of the large brewing corporations that do not highlight water savings have headquarters located in the United States. Water saving initiatives are mentioned in some cases, so the present research cannot conclude that water savings are not a focus area in US brewery operations.

Mapping water risks, water efficiency assessments and water reuse investments are among the core topics for the brewing sector. Some of the larger players have also started looking into watershed analysis and working proactively together with local stakeholders and NGOs to secure future water for both the society and the beverage industry.

3. Watershed management – not just a regulatory obligation but a strategic imperative for industries

Industries are increasingly recognising the importance of sustainable practices, particularly in the management of water resources. Watershed management is a critical aspect of this sustainability, ensuring that water use is balanced with the needs of the environment and local communities. This balance is not just a regulatory requirement but a vital social licence to operate, reflecting the industry's commitment to responsible stewardship of natural resources.

Industries rely heavily on water for various processes, from cooling and cleaning, to manufacturing and waste disposal. However, with this reliance comes a responsibility to manage water use sustainably.

Effective watershed management involves understanding the entire water cycle within a watershed, from precipitation and runoff, to groundwater recharge and discharge. By adopting a holistic approach, industries can minimise their impact on water resources and contribute to the health of the watershed.

At NIRAS we are seeing corporations engaging with local communities and stakeholders more often. Building trust and maintaining open communication channels are essential for gaining and retaining the vital social licence to operate. Industries must demonstrate their commitment to sustainable practices by actively involving communities in decision-making processes and addressing their concerns about water use and its impacts.

Industries could adopt a proactive approach to watershed management by participating in collaborative initiatives and partnerships. Working with government agencies, non-governmental organisations, and other stakeholders can lead to innovative solutions and shared benefits. These collaborations can enhance the resilience of watersheds, ensuring that they can support both industrial activities and the needs of local ecosystems.

Sustainable watershed management is not just a regulatory obligation but a strategic imperative for industries. By adopting sustainable practices, engaging with stakeholders, and participating in collaborative efforts, industries can secure their social licence to operate and contribute to the long-term health and sustainability of watersheds. This approach not only benefits the environment but also enhances the industry's reputation and ensures its continued success in a resource-constrained world.

Day Zero – Water shutdown in Cape Town, South Africa

The city of Cape Town literally ran out of water in 2018, forcing the shutdown of municipal water supplies. This crisis emerged due to severe droughts and mismanagement of water resources. Although efforts were made to avert Day Zero, it highlighted the urgent need for sustainable water management and conservation in South Africa – not least within the agriculture and large process industry sector.

3.1. Water sources – availability

Industries around the world rely on various water sources to meet their operational needs. Surface water, extracted from rivers, lakes and reservoirs, is one of the primary sources. However, the availability of surface water can be affected by seasonal variations and climate change, making it an unreliable source in some regions.

Groundwater, which accounts for approximately 99% of all liquid freshwater on Earth, is another crucial source for industries[4]. It provides a stable supply, especially in areas where surface water availability is scarce or fluctuates a lot. However, over-extraction of groundwater can lead to depletion and environmental issues, such as land subsidence and reduced water quality.

Desalination is an increasingly important source of water for industries, particularly in arid regions and coastal areas. This process involves removing salt and other impurities from seawater to produce fresh water. While desalination provides a reliable supply, it is energy-intensive and can have environmental impacts, such as brine disposal.

New water, also known as reclaimed or recycled water, is municipal treated wastewater that can be reused for industrial purposes. It is a growing concept especially in water-stressed regions such as India and South Africa, but it is also used in highly industrialised areas such as Silicon Valley in the USA. This sustainable practice reduces the demand for fresh water and minimises the environmental footprint of industrial activities. Treated effluents, which are by-products of industrial processes, can also be treated and reused, further enhancing water efficiency.

Rainwater harvesting – collecting roof water and run-off from paved areas – is another source, which in many industries can provide a good supplement to the traditional sources.

3.2. Water scarcity and drought risks

Water scarcity and droughts present significant challenges for industries worldwide and also pose a serious threat to biodiversity. As the demand for water continues to rise due to population growth and economic development, industries face increasing pressure to manage their water use sustainably and improve their local impact on biodiversity.

Water scarcity occurs when the demand for water exceeds the available supply, often exacerbated by inefficient water use and climate change. Droughts, which are prolonged periods of abnormally low rainfall, further strain water resources and disrupt industrial operations.

Industries that rely heavily on water, such as agriculture, manufacturing and energy production, are particularly vulnerable to water scarcity and droughts. These sectors may experience reduced productivity, increased operational costs and supply chain disruptions. For example, in agriculture, water shortages can lead to crop failures and reduced food production, impacting both the industry and global food security.

To mitigate these risks, industries adopt sustainable water management practices and are increasingly involving themselves in local watershed management. By jointly reducing overall water consumption in the area, as well as reducing their own water footprint, industries can ensure a more reliable water supply and minimise environmental impacts.

A lot of large corporations mitigate their own risks around water scarcity and droughts. By adopting sustainable water management practices in a broader perspective and engaging in collaborative efforts, industries can further secure their water supply for the future. This approach not only benefits the environment but also enhances the industry's resilience and reputation in a resource-constrained world.

NASA has published a global overview of groundwater storage trends for Earth's 37 largest aquifers, showing depletion and replenishment in millimetres of water per year[5]. The conclusion shows that more than half of the analysed aquifers have exceeded sustainability tipping points and are being depleted, and 13 of these are considered significantly distressed, threatening regional water security and resilience. The European Environment Agency has made predictions for Europe showing future changes in precipitation, which clearly shows that droughts in southern Europe will increase (Figure 2).

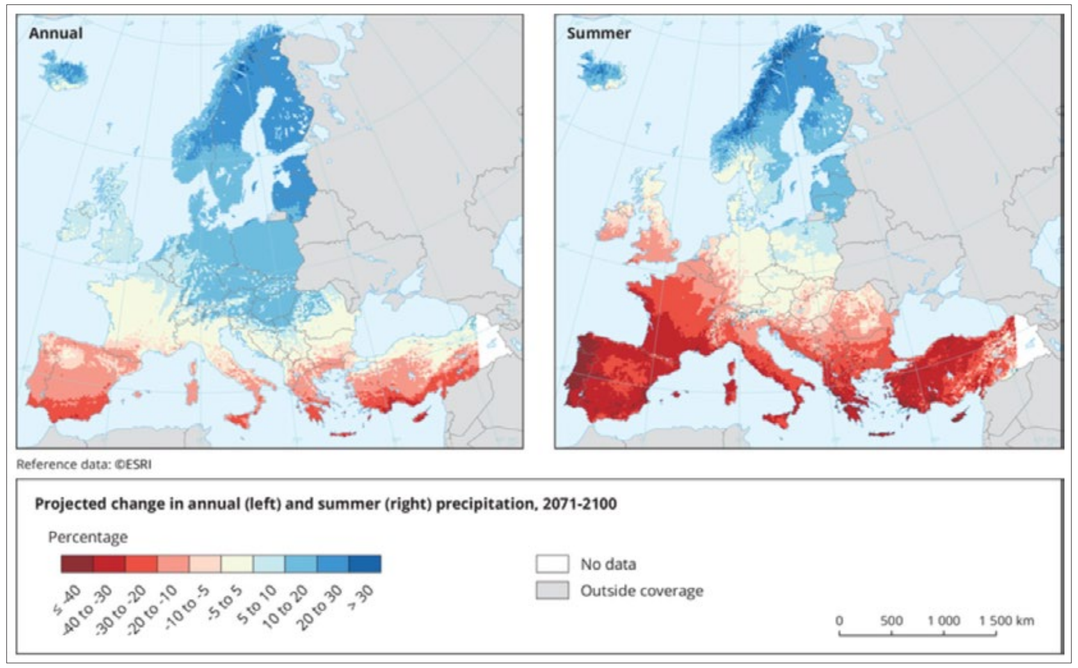


Figure 2 Projected change in annual and summer precipitation, EEA[5]

Life science is about to increase water consumption despite the high focus on savings

The world's largest life science industries increased water consumption by 3% compared to the previous reported year. The sector's growth, combined with acquisitions, are the main reasons for this finding, so some of the additional water consumption is due to mergers of minor companies.

The total water consumption for the 50 largest pharmaceutical companies is estimated to be above 500 million m^3, hereof +420 million m^3 confirmed in ESG reporting. 20% of pharmaceutical corporations did not specify actual water consumption for the two recent years in their ESG reporting. Obviously the figure has some uncertainty as some of the non-reporting corporations were very large. Nevertheless, there is generally a trend towards having water savings in focus and almost all corporations claim to reduce water use in their production.

The governing trend among life science industry is to improve treatment of wastewater due to the risk of pathogens and other active pharmaceutical ingredients (APIs) being discharged to the aquatic environment. Water efficiency, rainwater harvesting, and wastewater reuse used for cooling or boiler make-up or improved biodiversity through landscaping, are also common initiatives to decrease water footprint.

Some of the corporations have recently completed or are currently looking into geographical water risk assessments in order to prioritise their water management effort towards the most water stressed areas. Others still prioritise water as a fairly low or medium materiality impact. Generally, stringent legal requirements for water used in pharmaceutical industry often limits initiatives for reusing water within the sector. Pharmaceutical companies typically use municipal water for their production and are predominantly located in regions where steady 24/7 and reliable water supply is available.

3.3. Extreme events and flood risks – How industries can help protect and prevent

Extreme flooding events are becoming increasingly common worldwide, posing significant risks to local communities and industries. These events, driven by climate change, result in heavy rainfall, storm surges and rising sea levels, leading to widespread flooding and potential deterioration in water quality. Industries located in flood-prone areas are particularly vulnerable, facing potential disruptions to operations, damage to infrastructure and financial losses.

Flooding can also disrupt supply chains leading to delays in production and distribution. For industries such as manufacturing, energy and transportation, these disruptions can have cascading effects, impacting not only the companies themselves but also their customers and the broader economy.

To mitigate the risks associated with extreme flooding events, industries can adopt comprehensive flood management strategies. This includes conducting risk assessments to identify vulnerable areas (Figure 3), implementing flood defences such as levees and floodwalls, and designing facilities to withstand flood conditions. Additionally, industries could develop emergency response plans to ensure the safety of employees and minimise operational disruptions during flood events. Investing in resilient infrastructure is also crucial. This involves using flood-resistant materials, elevating critical equipment and incorporating drainage systems that can handle heavy rainfall. By enhancing the resilience of their facilities, industries can reduce the impact of flooding and ensure a quicker recovery.

Industries could participate in regional planning efforts, support the development of early warning systems and engage in community-based initiatives to enhance flood resilience. By working together, industries and communities can create a more robust defence against extreme flooding events.

In conclusion, the risk of extreme flooding events poses significant challenges for industries worldwide. We see global corporations more commonly adopting proactive flood management strategies, investing in resilient infrastructure and collaborating with stakeholders, in order to mitigate these risks and ensure long-term sustainability. This approach not only focuses on protecting their industrial operations but also contributes to the overall resilience of communities and economies in the face of climate change.

€10bn flooding impact estimated toward the industries in Valencia, 2024

On 29 October 2024, torrential rain hit Valencia with devastating impacts on people and society. The rain was caused by an isolated low-pressure area at high levels and brought over one year's precipitation to several areas in eastern Spain. The resulting floodwaters caused the deaths of hundreds of people and substantial damage to urban property, as well as industry. Valencia's industry secretary has estimated that damages suffered by companies in the region will reach more than €10bn.[6]

Figure 3 Example of flooding calculations (Scalgo-model) for an industrial site.

3.4. Watershed governance – Ensuring sustainable industrial water management

3.4.1. Stakeholder management

Effective watershed governance hinges on the active participation of diverse stakeholders, including industrial enterprises, local communities, regulatory bodies and environmental organisations. By fostering collaboration and transparent communication, we can ensure that industrial water usage aligns with broader environmental and social objectives.

Engaging stakeholders in decision-making processes helps to balance the needs of the industry with the sustainable management of water resources, ultimately leading to mutually beneficial outcomes.

3.4.2. Socio-economic assessment within your watershed

Analysis by NIRAS's experts in the production of this paper shows that leading companies find understanding the socio-economic landscape within their watershed crucial for devising effective watershed governance strategies. Industrial activities can significantly impact local economies and livelihoods, both positively and negatively. By analysing economic data and social dynamics, it is possible to identify potential risks and opportunities associated with industrial water use. This enables the development of tailored solutions that support economic growth, while safeguarding water resources for future generations. In-depth, socio-economic assessments can guide industries in adopting practices that contribute to the overall well-being of the watershed community.

3.4.3. Biodiversity and water-related rights

Preserving biodiversity and upholding water-related rights are fundamental components of robust watershed governance. Industrial operations must be designed to minimise ecological disruption and respect the water rights of all stakeholders, including indigenous communities and downstream users. The importance of integrating biodiversity conservation into industrial water management plans cannot be underestimated.

Industries are increasingly identifying and more importantly mitigating potential impacts on local ecosystems, ensuring compliance with environmental regulations and promoting sustainable water stewardship. By prioritising biodiversity and equitable water access, industries may contribute to the resilience and health of the overall watershed.

Water aspects play a very important role in the concept of Nature based Solutions (NbS[7]). NbS covers a range of actions modifying the ecosystems and introducing more nature. It is increasingly being considered as an integrated tool improving water quality, mitigating flooding risk, reducing nutrient load, combating desertification, restoring degraded land and soil, and not least, enhancing biodiversity.

4. Improving efficiency to optimise water usage in industrial operations

4.1. Water balance inside your fence

Effective water management within industrial plants contributes to sustainability goals and targets for operational efficiency. The aim of water balance involves monitoring and managing the inflow, usage and outflow of water within the plant boundaries. This includes assessing sources of water, such as groundwater, surface water and municipal supplies, and understanding how water is utilised in various processes. By maintaining a comprehensive water balance, plants can set the KPI targets and identify areas of excessive consumption, opportunities for conservation and potential for reuse, all of which contribute to overall water efficiency.

A holistic approach looking at operational water and energy consumption is recommended when setting targets. Some water efficiency measures reduce energy consumption but there are also some of the water-saving initiatives, which imply increased energy consumption.

The desired payback time of capital investments, including shadow prices, is also an essential management parameter to define prior to planning efficiency optimisations.

Shadow prices are often used when companies look at water and CO_2

A shadow price is an estimated monetary value assigned to an abstract or intangible commodity, e.g. "water". Shadow prices are used to reflect the real economic prices of goods and services after adjusting for distortionary market instruments like quotas, tariffs, taxes, or subsidies, and incorporating the societal impact of the respective good or service.

4.2. Reduce, Reuse, Recycle & Rethink water

The 4Rs concept – "Reduce, Reuse, Recycle, Rethink" – provides a strategic approach to improving water efficiency in industrial settings. Adopting a comprehensive water efficiency strategy that incorporates the principles of the 4Rs can lead to substantial improvements in resource conservation cost savings and environmental stewardship within industrial operations.

4.2.1. Reduce

Reduction focuses on minimising water usage through efficient processes and technologies. This involves optimising equipment, detecting and repairing leaks, and implementing best practices to ensure that water is used only where necessary and in the most efficient manner possible.

4.2.2. Reuse

Reusing water involves treating and repurposing wastewater for other processes within the plant. This approach can significantly decrease freshwater demand and reduce the volume of effluent discharged, contributing to both environmental and economic benefits.

4.2.3. Recycle

Recycling water means treating wastewater to a quality suitable for its intended purpose and then reintroducing it into the system. Advanced treatment technologies can enable the recycling of process water, cooling water, and even in some cases the water coming from raw materials, thereby reducing the reliance on external water sources.

4.2.4. Rethink

Rethinking water usage involves a fundamental reassessment of how water is utilised and managed. This includes exploring new technology and processes as well as innovative approaches such as industrial symbiosis, where water and resources are shared among neighbouring industries. By viewing water as a shared resource and fostering collaborative relationships, industries can enhance overall water efficiency and sustainability.

4.3. On-site industrial water efficiency reviews – A strong initial approach to improved water management

On-site industrial water efficiency reviews may serve as a strong critical tool to initiate analyses and improve water usage within a given industry. It is essential that such on-site industrial reviews combine water expertise with process expertise to ensure that the solutions provided comply with the specific requirements of the processes, which may include stringent hygienic standards, for example.

4.3.1. Combining water and process expertise

To conduct a successful on-site water efficiency review, it is essential to integrate both water and process expertise – and often also energy expertise. Water experts bring a deep understanding of water management, conservation techniques and regulatory requirements. Process experts, on the other hand, have intimate knowledge of the specific industry processes, operational requirements and any hygiene standards that must be met. This combined expertise ensures that proposed solutions are not only effective in reducing water consumption but also comply with industry-specific requirements.

4.3.2. Identifying water efficiency improvements

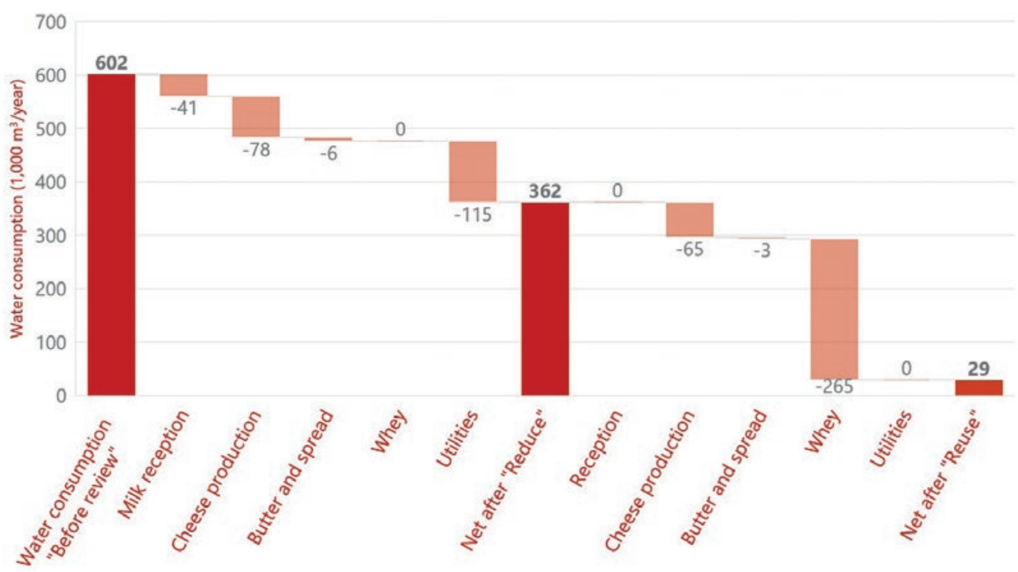
The primary goal of on-site industrial water efficiency reviews is to identify potential water efficiency improvements while taking due consideration of the economic consequences of the initiatives. This involves a detailed assessment of current water use patterns, including water sourcing, consumption, and wastage combined to generate multiple ideas for efficiency improvements.

The review process typically includes:

- Inspection of the production facility including utilities and water treatment
- Analysis of water flow and pressure levels
- Review of existing water management practices
- Identification of water wastage areas and generating a vast catalogue of ideas for water efficiency improvements

By pinpointing inefficiencies and areas of excessive water use, the review lays the groundwork for targeted interventions.

Water efficiency review conclusion of a dairy site visit



4.4. Prioritising efforts

Once potential improvements are identified, the next step is to prioritise efforts to decrease water consumption. This involves evaluating the feasibility and impact of each potential intervention.

Vital factors during the prioritisation to consider include:

- The potential reduction in water consumption
- Cost savings associated with reduced water use
- Rough estimated capital expenditure (CAPEX) needs and operational costs (OPEX)
- Compliance with industry standards and regulations
- Calculation of payback times (±50%) for each initiative also taking OPEX into consideration
- Conformity towards expectations from society and company ambition
- Operational implications and ease of implementation.

The importance and the thresholds of the different criteria should be based on the existing investment criteria of the company or potentially revisited at a workshop about investing in improvement of sustainability. Enforcing such investment can be done by, for instance, accepting longer payback and or using shadow prices to improve the business cases.

By prioritising efforts based on these criteria, industries can focus on the most impactful and feasible water efficiency measures.

4.4.1. Creating a roadmap

A key outcome of on-site water efficiency reviews is the creation of a roadmap for future planning including setting KPIs and defining target milestones. This roadmap outlines the steps needed to implement the identified improvements and achieve water efficiency goals.

Key components of the roadmap include:

- Detailed action plans for each water efficiency initiative
- Detailed estimation of CAPEX needs for implementation
- Calculation of payback times (±30%) for each initiative also taking OPEX into consideration
- Calculation of marginal cost for reducing one m^3
- Timeline for implementation and milestones.

The roadmap may serve as a strategic guide for industries helping the plant managers to systematically reduce water consumption, enhance sustainability and achieve long-term operational efficiency.

On-site water efficiency reviews and establishing roadmaps are vital for any industry aiming to improve water use and reduce operational costs. By combining water expertise with process expertise, these reviews ensure that solutions are both effective and compliant with industry-specific requirements.

The structured approach of identifying improvements, ranking efforts, and creating a detailed roadmap provides a clear path towards sustainable water management. With careful planning and implementation, industries can achieve significant water savings, contributing to environmental sustainability and economic efficiency.

4.4.2. Benchmarking multiple sites and against international best practices

Benchmarking water consumption is a pivotal practice for large industrial corporations aiming to improve their use of resources and sustainability efforts. By meticulously evaluating water usage across multiple sites and against international best practice, companies can identify inefficiencies, reduce wastage and implement best practices uniformly. This not only conserves a critical resource but also generates significant cost savings.

Where possible, benchmarking should extend beyond the plant level, delving into the various process units within an industrial plant to pinpoint specific areas for improvement. Such granular analysis ensures that every aspect of the operation is scrutinised, leading to more precise and impactful changes. Moreover, engaging employees and benchmarking fosters a culture of continuous improvement and accountability, driving environmental stewardship and compliance with regulations. Embracing this practice enhances corporate reputation, supports long-term operational resilience, and contributes to the global goal of sustainable water management.

5. Ultra-pure water, brine, ZLD and industry specific water challenges

Each industry has unique processes and standards, often particularly concerning hygiene. Life science works with GMP and rigorous water quality requirements, the Power-to-X industry requires ultra-pure water, and the food and beverage industry requires stringent hygiene standards to ensure food safety and quality. Hence, by integrating water and process expertise, on-site water efficiency reviews can tailor solutions to these specific needs, ensuring compliance while optimising water use.

5.1. Carbon neutrality and water for green hydrogen

Power-to-X industry is a highly specialised part of the energy industry producing hydrogen, ammonia or hydrocarbons based upon supply of CO_2. Still it is predominantly small companies, but we experience a growing interest from large corporations to look more into green hydrogen, to support the aim for carbon neutrality. Water is a vital ingredient to produce green hydrogen so we see a strong trend towards looking more into alternative water sources such as treated effluents from wastewater treatment plants. In many countries, treated effluents are the only available source of water provided for these new large water consuming industries.

5.1.1. Ultra pure water[9] and brine discharge

In 2024, NIRAS prepared a report for the Danish EPA reviewing process water treatment technologies and brine discharge with special focus on Power-to-X. The report created a lot of debate in the Danish water sector and most of the conclusions made are valid for other countries.

In this section, we present a few of the conclusions from the report in order to illustrate trends and situation around ultrapure water production[10] and not least the challenges we are facing towards brine discharge from such water purification plants. Water quantities within Power-to-X are typically larger than ultra-pure water production plants for other industries, but there are exceptions.

Overall there are a number of industry sectors which have standards related to the production of ultra-pure water, like life sciences[11] and electronics and semi-conductors.[12] With the strict requirements for ultra-pure water, many of the challenges are somewhat similar to the Power-to-X and hence equally relevant.

The ultra-pure water is typically produced via a series of treatment technologies, consisting of pretreatment, demineralisation and polishing. Pretreatments are typically ultrafiltration membrane filters, ion exchange. Demineralisation is typically reverse osmosis, multi-stage flash distillation or cation/anion exchanger. The polishing is a final removal of salts and dissolved substances, and may be second stage reverse osmosis, degassing, electro deionisation, mixed bed ion exchange or others depending on the actual quality requirement for the ultra-pure water. The quality requirements will depend upon the type of electrolyser[12] and the warranty requirement of the manufacturer.

The energy sector is the second largest water consuming industry after agriculture and likely to decrease

The International Energy Agency (IEA) estimate that the global energy sector consumes more than 55 billion m^3 water per year. Most of the water is used for cooling. Water withdrawals and consumption for bioenergy account for the irrigation of dedicated feedstock and water use for processing. Power-to-X (PtX) is still a minor water consuming part of the energy sector, but for every kg of hydrogen produced there is a theoretical need for 9kg of water. Looking into a future with potentially up to +2 billion ton of hydrogen per year on global scale, the PtX sector will require around 20 billion m^3 water per year.[13]

The cost for ultra-pure water treatment depends a lot on the water source. Table 1 presents Danish estimates of treatment cost in terms of CAPEX, OPEX, as well as 10-year TOTEX and cost per m^3 depending on source and size of the Power-to-X plant.

One of the key challenges for ultra-pure water treatment plants is that concentration of environmentally harmful substances increases when water is removed. So despite total quantities of discharged substances remaining, or for some substances even decreasing, the up-concentrated brine discharge might lead to exceeding discharge permits. The substances of typical concern are nutrients, metals, PAH[15], phenols, phthalates and PFAS.

Treatment technologies exist to remove some of these substances, but for others the treatment techniques are still fairly immature technology-wise, for example, when it comes to PFAS, and furthermore it depends on the type of water source. Table 2 provides an overview of the current technology matureness related to brine treatment.

Danish cost estimates The colour indicates estimated uncertainty on the cost estimations (green<30%; yellow=30-50%; orange=>50%)		CAPEX (million EUR)		OPEX (million EUR)		TOTEX (million EUR)		Cost pr m^3 (EUR/m^3)	
		50MW	1 GW	50MW	1 GW	50MW	1 GW	50MW	1 GW
Treated wastewater effluent									
Yellow	Ultra-pure water treatment	6.0	28.2	0.5	2.1	1.0	5.0	14.1	3.6
Yellow	Brine treatment with specific PFAS[14] challenges	1.1	5.4	0.2	1.3	0.3	2.0	4.3	1.3
Green	Brine treatment with diffuse PFAS challenges	0.9	3.8	0.2	1.0	0.3	1.3	3.9	0.9
Groundwater									
Yellow	Ultra-pure water treatment	4.7	20.8	0.3	2.0	0.7	4.0	10.1	2.9
Green	Brine treatment with no harmful substances	0.7	1.7	0.1	0.4	0.2	0.5	2.1	0.4
Surface water									
Yellow	Ultra-pure water treatment	5.6	26.1	0.4	2.0	0.9	4.7	13.4	3.4
Yellow	Brine treatment with diffuse PFAS challenges	0.9	3.2	0.2	0.7	0.2	0.9	2.8	0.7
Sea water									
Orange	Ultra-pure water treatment	11.4	46.9	0.9	4.7	2.1	9.4	29.5	7.0
Orange	Brine treatment	0.9	4.4	0.1	0.7	0.1	1.1	2.1	0.8

Table 1 Cost estimates for ultra-pure water treatment and brine treatment for Power to X depending on water source[8]

Technology	**Substances**	Brine from ultra-pure water treatment based on:			
		Treated wastewater effluent	Ground-water	Surface water	Sea water
Adsorption (AC[15])	COD[17], metals, PAH, phenols, phthalates	Green	Green	Green	Green
	PFAS	Yellow	Yellow	Yellow	
Adsorption (GFH[16])	Metals[18], Phosphorus, Silica	Green	Green	Green	Orange
Biological treatment	Nitrogen	Orange	Green	Orange	Orange
	COD	Green	Green	Green	
Chemical precipitation & flocculation	Metals, Phosphorus, particles[19], (COD)	Green	Green	Green	Yellow
Advanced oxidation processes	COD, (hazardous substances)	Green	Green	Green	
Ion exchange	Metals	Green	Green	Green	Orange
	PFAS	Orange	Green	Yellow	
Foam fractioning	Long chained PFAS [≥C6]	Orange	Green	Yellow	

Table 2 Technology maturity (Green=mature; Yellow= less mature; Orange=immature)[8]

5.2. Zero Liquid Discharge (ZLD)

With the growing sustainability focus, there is an increasing interest in looking at Zero Liquid Discharge. Currently, the trend is most obvious within Life Sciences but we have also experienced the interest for the ZLD concept within advanced manufacturing.

Several of the technical components in a ZLD plant are similar to the ultra-pure water treatment of treated wastewater effluents, but ZLD plants include water evaporation at the final stage, leaving a solid waste as the only discharge.

The energy consumption of the final stages of the ZLD plant is typically 60 – 90 KWh/m^3 treated.

The operating cost is therefore very much depending upon the cost of electricity, but also the disposal costs for the solid waste might have a significant impact. However, in some circumstances the dried material might be an income if the salts contains valuable metals, nutrients.

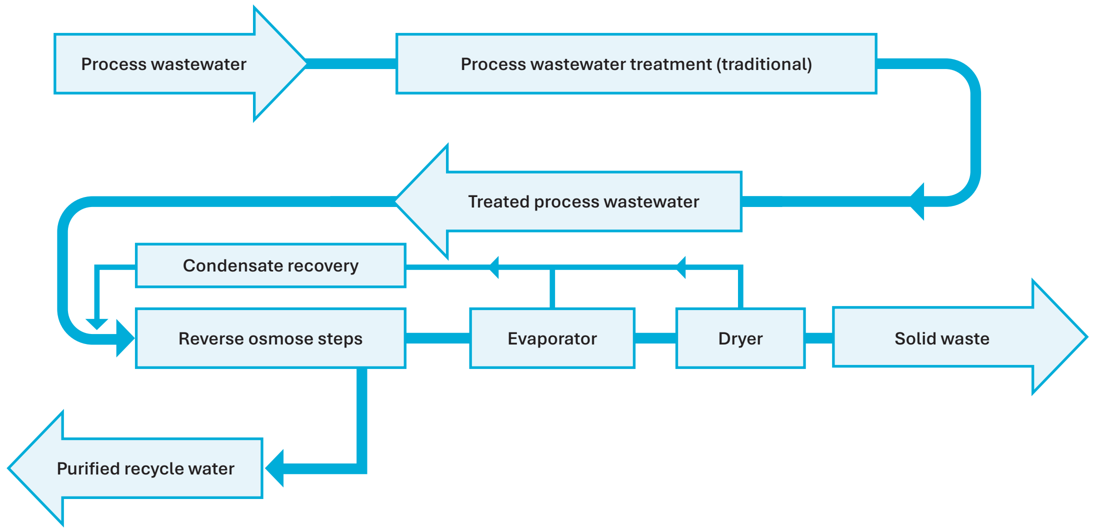


Figure 5 Example of simplified Zero Liquid Discharge (ZLD) Plant

5.3. Water safety and hygienic requirements

Different industry sectors have different requirements for water safety and hygienic standards, and these even vary from country to country. Likewise large organisations have global internal minimum standards. Within the life science sector there is a very high focus on hygienic standards due to the use of water in various sensitive processes ensuring it is free from any hazardous substances.

The highest water quality-standard within Life Science is Water for Injection (WFI)[20]. Continuous monitoring and testing of water quality are essential to ensure compliance and there are mandatory requirements for documentation, traceability and accountability.

Hence, proper hygiene practices must be complied with both related to handling and storing water to prevent deterioration of the water quality, and clean utility requirements includes using sanitised equipment and clean environments.

Strict requirements also exist within other industrial sectors, like the food processing industry, where water is used for various purposes, including washing food, cleaning equipment and food preparation. Generally it is important to secure the highest quality of water used in any processes, which directly impacts safety through human consumption[21].

6. Supply chain water management in industries – How to ensure sustainable water usage on all levels

Effective water management within supply chains is essential for ensuring sustainability and mitigating long term risks associated with water scarcity and climate adaption. One of the most water-reliant is the food industry, where the essential supply chain element of agriculture alone accounts for 70% of global water use. However, other supply chain elements may also need a significant amount of water, adding to the product's total water footprint. This underscores the importance of strategic water management practices to maintain the delicate balance between production demands and environmental stewardship.

6.1. Water auditing of your supply chain – a way to identify usage and waste

Conducting a water audit is a foundational step in understanding and managing water usage within a supply chain. Water auditing involves a comprehensive assessment of water withdrawal, consumption and discharge at each stage of the supply chain, and can be done by dedicated internal experts or by external specialists. The aim of the process is to help identify the most important inefficiencies and potential areas for water savings, as well as risks related to water availability and quality throughout the entire supply chain.

Water auditing may improve efficiency by identifying and addressing areas of high water usage and waste, industries can optimise their processes and reduce unnecessary consumption, and lead to cost savings. Efficient water use translates to lower utility bills and reduced costs associated with water treatment and disposal. Risk mitigation helps understanding water-related risks allowing companies to develop strategies to mitigate potential disruptions in their supply chain due to water scarcity or regulatory changes. Finally, by demonstrating a commitment to sustainable water management, companies can enhance their reputation among consumers, investors, and regulators.

6.2. Encouraging regenerative agriculture – a key element in water conservation

Several large food and beverage corporations are looking into promoting regenerative agriculture. Regenerative agriculture is an approach to farming that focuses on restoring and enhancing the health of the ecosystem. This practice not only improves soil health and biodiversity but also plays a significant role in water conservation.

Key practices in regenerative agriculture are:

- Cover cropping: Planting cover crops helps prevent soil erosion, improves soil structure, and enhances water retention
- Crop rotation: Rotating different crops can reduce pest and disease outbreaks, improve soil fertility and reduce water stress
- No-till farming: Minimising soil disturbance helps maintain soil moisture and reduces the need for irrigation
- Agroforestry: Integrating trees and shrubs into agricultural landscapes can enhance water infiltration and reduce runoff.

From a water perspective, regenerative agriculture improves water conservation, while healthier soil with better water retention reduces the need for irrigation and helps to maintain local water cycles. Climate resilience by improved soil health enhances the resilience of crops to climate variations, reducing the risk of crop failure due to drought or flood. Carbon sequestration as regenerative farming practices help sequester carbon in the soil, contributing to climate change mitigation. Increased biodiversity, which supports ecosystem stability and resilience, promotes a healthier environment.

6.3. Transparency and awareness – How to drive collective action

Transparency and sustainability awareness are critical components of effective supply chain water management. By fostering a culture of openness and education throughout the entire supply chain, industries can drive collective action towards sustainable water use.

The strategies for enhancing transparency and awareness typically include:

- Reporting and disclosure: Regularly reporting on water usage, risks, and management practices helps stakeholders understand a company's water footprint and sustainability efforts
- Stakeholder engagement: Engaging with suppliers, customers, and local communities to raise awareness about the importance of water conservation and the role they can play
- Technology and Innovation: Leveraging technological advancements, such as real-time water monitoring and predictive analytics, to enhance transparency and decision-making
- Education and training: Providing training programs for employees and suppliers to build capacity and drive best practices in water management.

Transparency and sustainability awareness creates trust with stakeholders and enhances the company's credibility. Proactive disclosure and engagement help ensure compliance with water-related regulations and standards. Collaborative solutions increase awareness and facilitate collaboration among industry players to develop innovative solutions for water management challenges. Finally, companies that demonstrate leadership in water sustainability can often gain a competitive edge in the market.

Effective supply chain water management is essential for industries seeking to ensure sustainability, resilience and long-term success. By conducting supply chain water audits, encouraging regenerative agriculture, and fostering transparency and awareness, companies can significantly reduce their overall water footprint and contribute to the preservation of the vital water resources.

7. Good water governance – Sustainable water management for the future

Good water governance practice is essential for the sustainable management of water resources, ensuring that water is used efficiently, equitably, and sustainably and industrial wastewater discharges are limited to a minimal environmental impact. As water resources become increasingly stressed due to factors such as population growth, climate change and industrial activity, the need for robust governance frameworks has never been more critical. Many guidelines and standards for good water governance exist around the world, but this document outlines for inspiration some of the most used principles for good water governance: Water Stewardship, CDP Water Security, Net Positive Water Impact (NPWI), EU CSRD and Taxonomy, and Science Based Targets for Water.

7.1. Water stewardship – Safeguarding the water resources

Water stewardship refers to the responsible management and use of water resources in a way that is socially equitable, environmentally sustainable and economically beneficial. It involves collaboration among various stakeholders, including governments, businesses and communities, to manage water resources effectively. Water stewardship aims to balance competing demands for water, while ensuring the long-term sustainability of water ecosystems. Key principles of water stewardship[22] include understanding and managing water risks, promoting water efficiency, protecting water quality and engaging stakeholders in water management decisions. The Alliance for Water Stewardship provides a global standard for water stewardship.

7.2. CDP Water Security program

The CDP Water Security[23] program is a global initiative that encourages companies to disclose their water-related risks, opportunities and impacts. The program aims to drive corporate transparency and accountability in water management by providing a standardised framework for reporting water-related data. Through the CDP Water Security program, companies can identify and manage their water risks, set targets for water use and quality, and demonstrate their commitment to sustainable water management. The program also enables investors, policymakers and other stakeholders to assess and compare the water performance of companies, driving improvements in water governance across industries.

7.3. Net Positive Water Impact (NPWI)

Net Positive Water Impact (NPWI)[24] is a concept under the UN Global Compact. NPWI goes beyond reducing water use and pollution to create a net positive impact on water resources. It involves companies and organisations taking proactive measures to restore and replenish water ecosystems, improve water quality, and enhance water availability for communities and the environment. Achieving NPWI requires a comprehensive approach to water management, including reducing water withdrawals, enhancing water efficiency, treating wastewater, and investing in water conservation projects. By striving for NPWI, companies can contribute to the resilience and sustainability of water resources, benefiting both their operations and the broader community.

7.4. EU CSRD and taxonomy

The European Union's Corporate Sustainability Reporting Directive (CSRD)[25] and Taxonomy Regulation[26] are key regulatory frameworks aimed at promoting sustainability and transparency in corporate reporting. The CSRD requires companies to report on their environmental, social and governance (ESG) impacts, including their water management practices. The EU Taxonomy provides a classification system for sustainable economic activities, including those related to water management. By aligning their water governance practices with the EU CSRD and Taxonomy, companies can enhance their sustainability performance, meet regulatory requirements and attract sustainable investments.

7.5. Science Based Targets for Water

Science Based Targets for Water (SBTi)[27] is an initiative that provides companies with a framework to set ambitious and science-based targets for water management. The SBTi aims to align corporate water targets with the latest scientific understanding of water resources and the planetary boundaries within which they must be managed. By setting science-based targets for water, companies can ensure that their water use and management practices are sustainable and contribute to the long-term health of water ecosystems. The SBTi also promotes transparency and accountability in water governance, encouraging companies to report on their progress and achievements.

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The present white paper has been published by NIRAS for the inspiration to improve industrial water management for both large corporations and small-medium size industries.

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[1] In the present white paper we have used the term "water" broadly, i.e. covering water supply, treated ultra-pure water, stormwater, sewage water as well as treated wastewater.

[2] "COW water" is "Condensate Of Whey water" which is generated when milk consisting of ca. 90% water is evaporated or up-concentrated in connection with e.g. cheese, and powder production.

[3] Materiality assessments of water impacts has been gathered for a number of large industries within brewery, dairy and life science industry from their sustainability reporting. It is noted that several large companies do not present their assessments in a matrix and even for the ones that do, some interpretation has been necessary in order to align the various reporting principles and not least adjust to the different scales to achieve the present comparisons in a single uniform materiality assessment matrix. It is further noted that the term "Water" in several reports is reported as either "Water", "Water management", "Water resources", "WASH", "Water & Wastewater" and more. All has been considered as "Water" in the graph.

[4] UN World Water Development Report 2022 | UN-Water

[5] https://www.eea.europa.eu/en/analysis/maps-and-charts/projected-changes-in-annual-and-6

[6] https://www.commercialriskonline.com/valencia-floods-set-to-be-biggest-nat-cat-loss-ever-in-spain/

[7] https://www.un.org/sites/un2.un.org/files/2021/04/nature-based-solutions-20110426.pdf

[8] https://mst.dk/media/oxqp5pwj/bilag-1-rensning-af-processpildevand-fra-rentvandsfabrikker-til-power-to-x.pdf

[9] Ultra-pure water is often defined by conductivity<0,06 µS/cm plus requirement related to certain substances Cu, Fe etc

[10] https://www.who.int/docs/default-source/medicines/norms-and-standards/guidelines/production/trs970-annex2-gmp-wate-pharmaceutical-use.pdf?sfvrsn=39eb16b8_0

[11] https://www.astm.org/d5127-13r18.html

[12] Electrolysers split water into hydrogen and oxygen

[13] IEA (2023), Global water consumption in the energy sector by fuel and power generation type in the Net Zero Scenario, 2021 and 2030, IEA, Paris https://www.iea.org/data-and-statistics/charts/global-water-consumption-in-the-energy-sector-by-fuel-and-power-generation-type-in-the-net-zero-scenario-2021-and-2030, License: CC BY 4.0

[14] PFAS = Per- and polyfluoroalkyl substances consist of carbon-fluorine chains, which is one of the strongest bond implying it degrade poorly in the environment.

[15] PAH = Polycyclic Aromatic Hydrocarbons (PAH) are both naturally occurring or man-made chemicals.

[16] AC = Activated Carbon; GFH = Granular Ferric Hydroxide

[17] COD = Chemical Oxygen Demand is the measure of oxygen required to chemically oxidize the organic material and inorganic nutrients.

[18] [As, V, Mo, Pb, Cu, Zn, Fe, Al]

[19] Particles are usually organic material

[20] Life Science requirements for "Ultra-pure water" (http://www.uspbpep.com/ep60/water%20for%20injections%200169e.pdf). Note that there are different requirements for "water for injection" and "purified water" and requirements vary depending on country.

[21] EU Directive 98/83/EC on the quality of water intended for human consumption https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:31998L0083

[22] https://a4ws.org/

[23] CDP formerly known as the Carbon Disclosure Project: https://www.cdp.net/en/water

[24] https://ceowatermandate.org/resilience/net-positive-water-impact/

[25] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32022L2464

[26] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32020R0852

[27] https://sciencebasedtargetsnetwork.org/about/hubs/water/

Dairy sector decreases total water withdrawal of 2% globally

There is a general trend to improve water management practice within the global dairy sector. Reuse of water inside the processes (CIP boilers) and not least also utilising COW water to priority initiatives for achieving water savings in dairy industry.

Total water withdrawal from 22 large dairy groups show thatTotal global reductions compared to previous years reporting was 2%.

Unfortunately only around 50% of the largest global dairy groups report on actual water withdrawal from municipal water, or own water production from groundwater, surface water or rainwater harvesting within the recent two years.

In particular, US based companies are reluctant to disclose their sustainability achievements or simply report on % reduction and few report total withdrawal volumes.

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