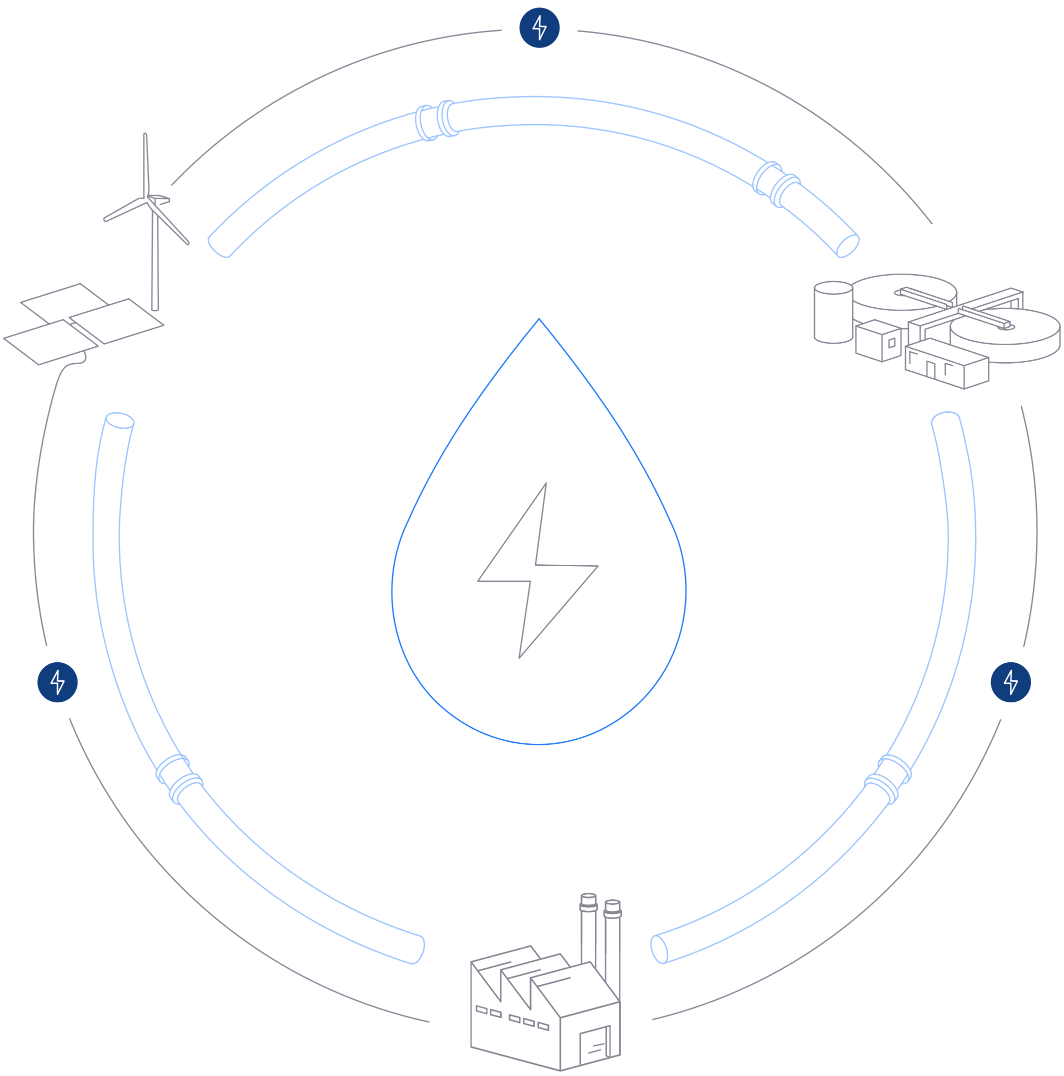
Danfoss Impact
No. 7

The potential of the water-energy nexus

Tapping into efficiency



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Brief

Drawing on empirical evidence and data from various credible sources, Danfoss Impact Issue No. 7 emphasizes the critical importance of seeing water and energy as interdependent resources. It highlights technologies with incredible energy-, water-, emissions-saving potentials, which today are scarcely implemented across the water sector and end uses despite widespread accessibility and favorable payback times.

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The views expressed in this paper are those of Danfoss. Their completeness and accuracy should not be attributed to any external reviewers or entities.

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Foreword

Water and Energy — how efficiency links them both

Water scarcity is one of the defining challenges of our time and it impacts us all. According to the Global Commission on the Economics of Water, the global water demand is set to outpace supply by 40% as early as 2030.[1] Already today, more than two billion people live without access to safe drinking water.[2]

One of the biggest challenges of global water management — which is not discussed nearly as much as it should be — relates to energy. **We're managing our energy use for water in an inefficient — and expensive — way, wasting far more than necessary.** We can change that!

According to the International Energy Agency (IEA), the global water sector accounts for 4% of all electricity use.[3] This energy is used to produce and treat water, pump it through networks of pipes, and deliver it to homes, farms, industries, and beyond. But after decades of underinvestment in the sector, we are putting unsustainable pressure on the critical infrastructure that manages this vital resource.

Without urgent action to address inefficiencies in how we manage the touchpoints in our water and energy systems, high-income countries risk losing up to 8% of GDP by 2050.[4] For the US, that's equivalent to almost one-third of government spending in 2024.[5]

The good news is that incredible potential exists today to increase the efficiency, resilience, and economic competitiveness of the water sector.

Many structural factors fueling the water crisis still remain hidden from public view: the steady drip of leaky pipes, outdated infrastructure, and the excessive energy consumption of our water systems. To patch the holes in our leaky, inefficient water systems, we must first fix the policies we've created to manage, protect, and develop them. This requires that governments, companies, and civil society alike work together to build efficient and resilient water systems for a more prosperous future. This is the primary focus of this paper.

Beyond the immediate impact on human health, water scarcity also means that industries across the globe are struggling to access water for production, posing a major challenge to industrial competitiveness.

But it doesn't need to be this way.

Whether in desalination, distribution networks, irrigation, or wastewater treatment, **technological solutions already exist to strengthen both water and energy efficiency across all phases of the water cycle.** This paper showcases the impact of existing technological solutions and highlights the political relevance of the water-energy

> "The good news is that incredible potential exists today to increase the efficiency, resilience, and economic competitiveness of the water sector"

nexus. It outlines where energy use in the water cycle is concentrated, which solutions exist to reduce water and energy waste, and how effective policy can bridge the gap between ambition and implementation.

Above all, **this paper calls for a shift in perspective amongst policymakers — to see water and energy not as separate challenges, but as deeply interconnected systems,** where efficiency in one unlocks efficiency and resilience in the other. To optimize the water-energy nexus, we recommend policymakers act on four fronts: to cut waste, boost efficiency, go digital, and make water count. The best part is that this can all be done with solutions that already exist. Now is the time to scale them to strengthen human well-being, increase climate resilience, ensure economic security, and accelerate industrial competitiveness. Let's get to work.

Kim Fausing
President & CEO, Danfoss

By 2030, global water demand will outpace supply by 40% — a challenge we cannot afford to ignore.

Only got 2 minutes?

1

Water waste is amplifying the climate crisis and threatening economic resilience

Current practices and infrastructure for water management are both inefficient and insufficient. **By 2040, the water sector's energy consumption is expected to more than double, while the energy sector's water demand could rise by almost 60%.**[6] Without rapid improvement in the energy efficiency of these systems, economic decline, climate disasters, and political instability will become more commonplace. On this front, **addressing the water-energy nexus is critical.** Through more efficient technologies for pumping, treatment, heating, and cooling, as well as smarter controls and digital monitoring, it is possible to reduce both energy costs and emissions while strengthening the resilience of our water systems.

2

Inefficient water consumption is draining the world's freshwater resources

Inefficient technologies and outdated processes mean that nearly all industries are consuming water at unsustainable rates. For example, growing demand for data processing has led to a corresponding growth in the energy and water consumption of data centers. The IEA estimates that **data centers today consume around 560 billion liters of water per year globally** — a number which could rise to around 1,200 billion liters per year in 2030.[7] That's six times the EU's total freshwater abstraction in 2022.[8] With closed-loop liquid cooling systems, however, companies can drastically reduce both the water and energy footprint of data centers.[9] Similarly, the semiconductor industry is highly water intensive. Despite this, 40% of global semiconductor manufacturing sites will be located in regions facing high or extreme water stress between 2030 and 2040.[10] This is a risky overlap between heavy water demand and growing water scarcity that could put industrial resilience at risk.

3

Investments in the water sector are needed to boost competitiveness and security

Water is crucial to competitiveness and security. As climate change worsens, **reduced access to clean water, sanitation, and declining water storage could cause high-income countries to see an 8% reduction in their GDPs by 2050.**[11] **For the US, 8% of GDP was equal to almost one-third of government spending in 2024.**[12] **Lower-income countries could experience a more acute reduction of 10-15%.**[13] Despite this, countries are losing significant amounts of treated water in leaky distribution networks. In the US, leaking pipes lost the equivalent of USD 7.6 billion worth of treated water in 2019 — a rate which is expected to increase to USD 16.7 billion by 2039.[14] Investments in existing solutions such as sensors, pumps, and variable speed drives can reduce water loss and increase the energy efficiency of water distribution networks.

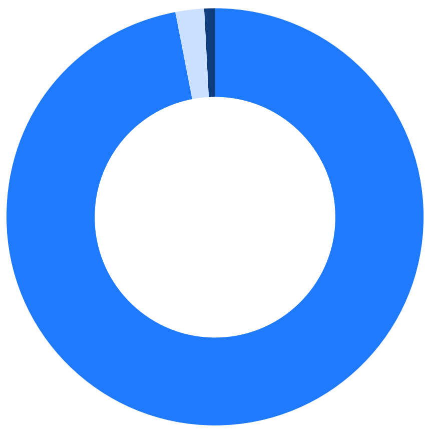
4

Water scarcity and rising demand require more energy-efficient forms of water management, treatment, and production

By 2030, global water demand is set to outpace supply by 40%.[15] To meet this demand, many regions will need to increase supply with energy-intensive methods of water production — namely desalination and wastewater treatment. Increasing the efficiency of these processes will be essential to limiting the impact on local water and energy systems, as well as on local environments. For example, if all existing desalination plants worldwide were retrofitted to operate at the current technological potential (2.0 kWh/m^3), it could bring **financial savings of EUR 34.5 billion and reduce CO_2 emissions by 111 million metric tons.**[16] Similarly, a wastewater treatment plant in Chennai, India saved roughly 22% of its energy use simply by implementing an existing technology: variable speed drives. Scaling this potential everywhere is essential to meet rising demand.

Water's intimate bond with energy

Figure 1
The distribution of water across oceans, glaciers and natural fresh sources[20]



- Oceans 97.2%
- Glaciers 2.15%
- Groundwater, lakes & rivers, soil moisture & atmosphere 0.65%

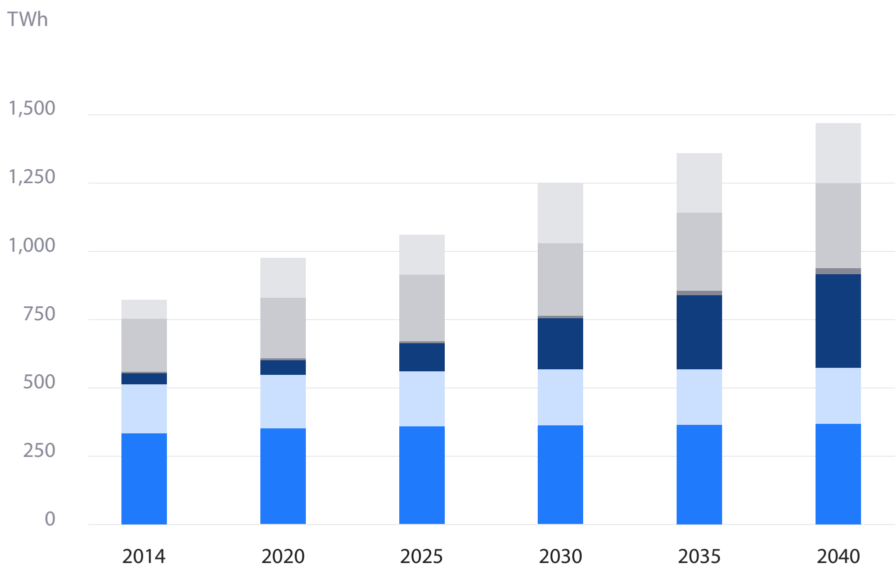
From a young age, we are taught that water makes up roughly 70% of Earth's surface. And it's true: water is one of our planet's most abundant resources. However, only a small portion of that water is available in a form we can actually use. In fact, only 3% of all water is freshwater, and just a fraction of that is accessible for human use (see Figure 1).[17] Essential for drinking water, food production, industrial processes, and sanitation, **ensuring reliable and sufficient access to freshwater is fundamental to human health, economic competitiveness, and long-term security.**

However, this precious resource is increasingly under pressure. Climate change is disrupting the water cycle, with severe implications for freshwater availability. One key concern is groundwater, which supplies half of all water worldwide withdrawn for household purposes and supports over 25% of global irrigation.[18] It is being depleted faster than it is replenished, and climate change is making things worse. Rising temperatures and shifting precipitation patterns are reducing groundwater recharge, threatening the long-term sustainability of this vital resource.[19]

Moreover, the systems and practices currently in place to manage Earth's freshwater resources are also incredibly inefficient. This is in part due to a lack of knowledge and transparency caused by weak or insufficient data. The result has been a **systematic underinvestment in the water sector, which has led to cracks — both figurative and literal — in water infrastructure.** In the US, leaking pipes lost the equivalent of USD 7.6 billion worth of treated water in 2019 — a rate which is expected to increase to USD 16.7 billion by 2039.[21] Similarly, in Europe, most EU Member States will need to spend between EUR 500-1,000 more per person in total by 2030 on water supply and sanitation to comply with existing water regulations.[22]

Finally, **water scarcity is in part caused by inefficient use of energy in the water sector itself.** The global water sector accounts for 4% of global electricity use,[23] much of which is produced with fossil fuels. The emissions from those fossil fuels go on to contribute to climate change, which in turn drives greater water-related crises. To both reduce the water sector's greenhouse gas emissions while boosting its resilience, it's crucial that decision makers focus on the energy efficiency of each step of the water cycle. This starts by understanding the relationship between water and energy.

Figure 2
Electricity consumption in the water sector by process, 2014-2040[25]



- Supply*
- Distribution
- Desalination
- Re-use
- Wastewater treatment
- Transfer

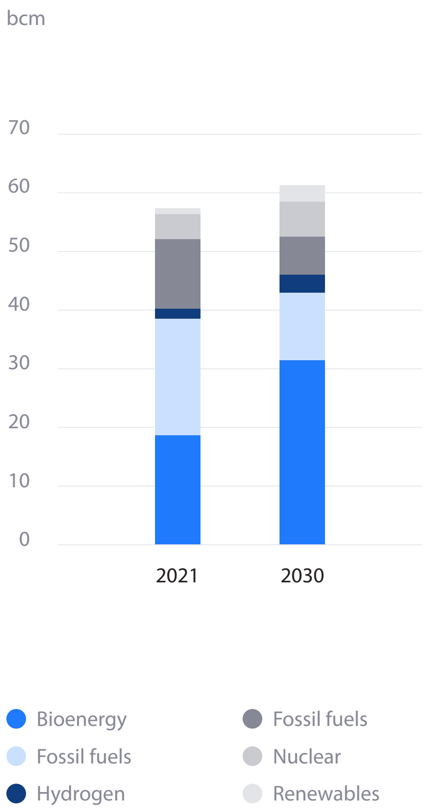
The water-energy nexus

Water does not get extracted, produced, treated, delivered, or consumed on its own: it requires energy. As populations grow and water requirements intensify, the energy demand of the water sector is rising sharply. **By 2040, the amount of energy used in the water sector is projected to more than double.**[24] The rising energy use is largely attributed to greater demand for wastewater treatment and desalination (see Figure 2).

The surge in energy consumption within water systems highlights a key opportunity for improved energy efficiency. Through more efficient technologies for pumping, treatment, heating, and cooling, as well as smarter controls and digital monitoring, it is possible to reduce both energy costs and emissions while strengthening the resilience of our water systems.

By 2040, the amount of energy used in the water sector is projected to more than double

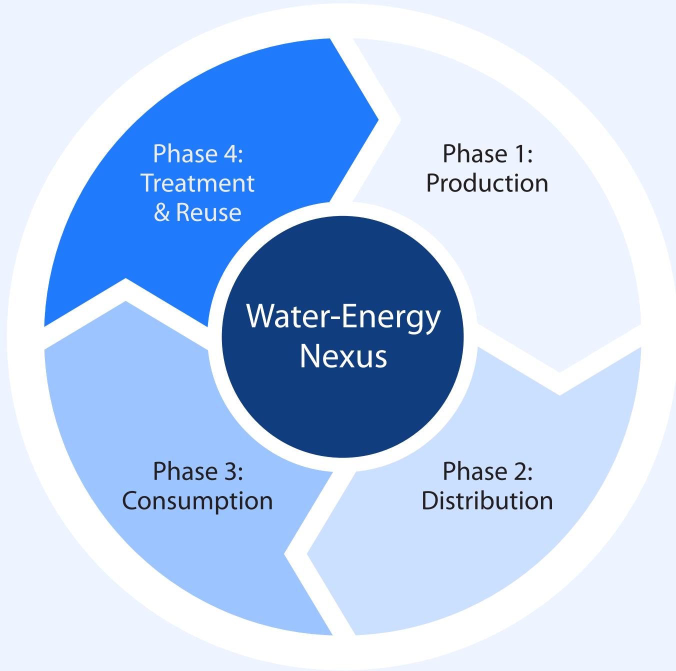
Figure 3
Global water consumption in the energy sector by fuel and power generation type in the Stated Policies Scenario, 2021 and 2030[28]



Moreover, just as energy is essential for water, water is essential for energy. The energy sector relies heavily on water for cooling power plants, generating electricity through hydropower, refining fuels, and supporting crops for bioenergy. **Today, the energy system accounts for approximately 14% of global water withdrawals,** making it one of the largest users of freshwater worldwide.[26] The need for water within energy production could grow by almost 60% by 2040.[27] Figure 3 shows just how much water is consumed in the energy sector by fuel and power generation type in 2021 and 2030.

Energy systems rely heavily on water, creating significant vulnerabilities. During droughts or heatwaves, power plants may have to reduce output or even shut down when cooling water becomes scarce. At the same time, water systems are consuming increasing amounts of energy for pumping, treatment, and distribution. The mutual dependency between the two vital resources is known as the water-energy nexus.

Figure 4
The four phases of the water-energy nexus



Understanding the water-energy nexus

This paper will use the economic life cycle of water as a framework for understanding the interconnected relationship between water and energy. Figure 4 above showcases the economic life cycle of water, divided into four key phases:

Phase 1: Production

Water production represents the first phase of the cycle. This involves both "conventional" water production (e.g., freshwater abstraction) and "unconventional" production (e.g., desalination). These processes require substantial energy input and therefore put an immense strain on our energy systems. At the same time, our energy systems rely heavily on water, both for cooling combustion processes but also as a source of energy, such as in hydropower and hydrogen production.

Phase 2: Distribution

Once produced, water must navigate a distribution network to reach end consumers. This distribution process demands energy for pumping, maintaining pressure, and ensuring water quality throughout the system.

Phase 3: Consumption

The third stage is the consumption of water across various sectors — especially in high-demand sectors and use cases such as agriculture, industry, and data centers. Energy is required to heat, pump, and disperse water during consumption, while water can also be utilized to absorb and transfer energy, like in liquid cooling systems for data centers or space heating and cooling through district energy systems.

Phase 4: Treatment & Reuse

Crucially, the cycle does not end at consumption. After use, wastewater often needs to be treated, and in many cases, has the potential to be reused. These are widely employed yet energy-intensive processes, meaning efficiency gains can bring considerable water and energy savings across the sector.

This circular approach highlights the importance of thinking about water and energy together, recognizing that efficiency in one part of the cycle can positively impact the entire system.

Three actions to address waste in the water cycle

Addressing water and energy waste in the water cycle requires that companies, utilities, policymakers, and regulators take three key actions:

Lower demand

Lowering demand for water is an essential step in limiting both water and energy waste. This is particularly relevant in the **consumption** phase. By consuming only what is truly needed, we can limit the strain on freshwater resources and reduce the need to produce water through energy-intensive processes. This is true for end-use water demand as well as in particularly water-intensive sectors such as industry and agriculture. Consuming only what is needed also reduces water and energy consumption in all up- and downstream phases of the water cycle, as we will need to produce, distribute, and treat less water. In practice, demand reduction means increasing awareness of water consumption amongst end users, planning for a reduction in water demand by better designing homes, urban spaces, or land use in general. Similarly, it means retrofitting or upgrading existing water infrastructure and using existing efficiency solutions in new installations.

Reduce waste

There are incredible amounts of water being wasted in the distribution of water. Currently, we are producing and distributing far more water than we actually use, and much of it is lost through leakages caused by inefficient pressure management and aging infrastructure in **distribution** networks. Similarly, increasing the energy efficiency of water processes can bring significant energy-, emissions-, and economic savings. Addressing the water waste is critical to reducing the amount of energy and resources needed to meet water demand (see p. 37 for more).

Supply efficiently

By applying existing energy-efficiency solutions to existing water infrastructure and by improving monitoring systems, many processes in the water cycle can be optimized to run in a more efficient way. Less energy will be needed to provide the same amount of water. When local freshwater abstraction cannot meet demand, it will be necessary to supply it through alternative methods. This means resorting to more energy-intensive forms of production such as desalination, as well as increased wastewater **treatment and reuse.** To minimize their pull on the energy system, these processes should be optimized for maximum efficiency.

The cost of not addressing the role of energy in the water cycle

Neglecting the water-energy nexus carries significant financial and competitiveness risks. Industries that rely heavily on both resources — such as manufacturing and resource extraction — face rising costs when inefficiencies go unaddressed. For example, **water-related issues have already led to a USD 9.6 billion increase in costs for the power generation sector worldwide,** largely due to increased operating expenses.[29] Moreover, as climate change worsens, **reduced access to clean water, sanitation, and declining water storage could cause high-income countries to see an 8% reduction in their GDPs by 2050.**[30] **For the US, 8% of GDP was equal to almost one-third of government spending in 2024.**[31] **Lower-income countries could experience a more acute reduction of 10-15%.**[32]

But the costs are not only financial or environmental: they are also deeply linked to human health and geopolitical security. When either water or energy becomes unaffordable or inaccessible, households can face economic hardship and public infrastructure becomes increasingly strained. Failing to manage our energy and water resources can even increase the risk of conflict as resource competition grows.[33] This is especially true in regions that depend on imported energy and shared water sources. **Strengthening security and building resource resilience starts with recognizing and addressing the water-energy nexus.**

Phase 1

Production

In most cases, before water can be used, it must be produced — whether through freshwater withdrawal or desalination of saltwater. While production and treatment (read more on treatment in Phase 4 on p. 36) of water is necessary to ensure it has the correct properties for various end uses, these are oftentimes energy-intensive processes that use inefficient equipment. Desalination, for instance, accounts for 26% of all energy used in the global water sector.[34] As water stress increases, so will the demand for desalination. And while there are many steps to take before resorting to producing water through desalination, focusing on energy efficiency will make desalination a reasonable solution to ensure a sufficient water supply.

This section presents key solutions for increasing the efficiency of water production systems to supply efficiently, with a particular focus on increasing the efficiency of the fastest growing method of water production: desalination. First, however, it discusses some common challenges in the management of existing freshwater resources.

Freshwater withdrawal

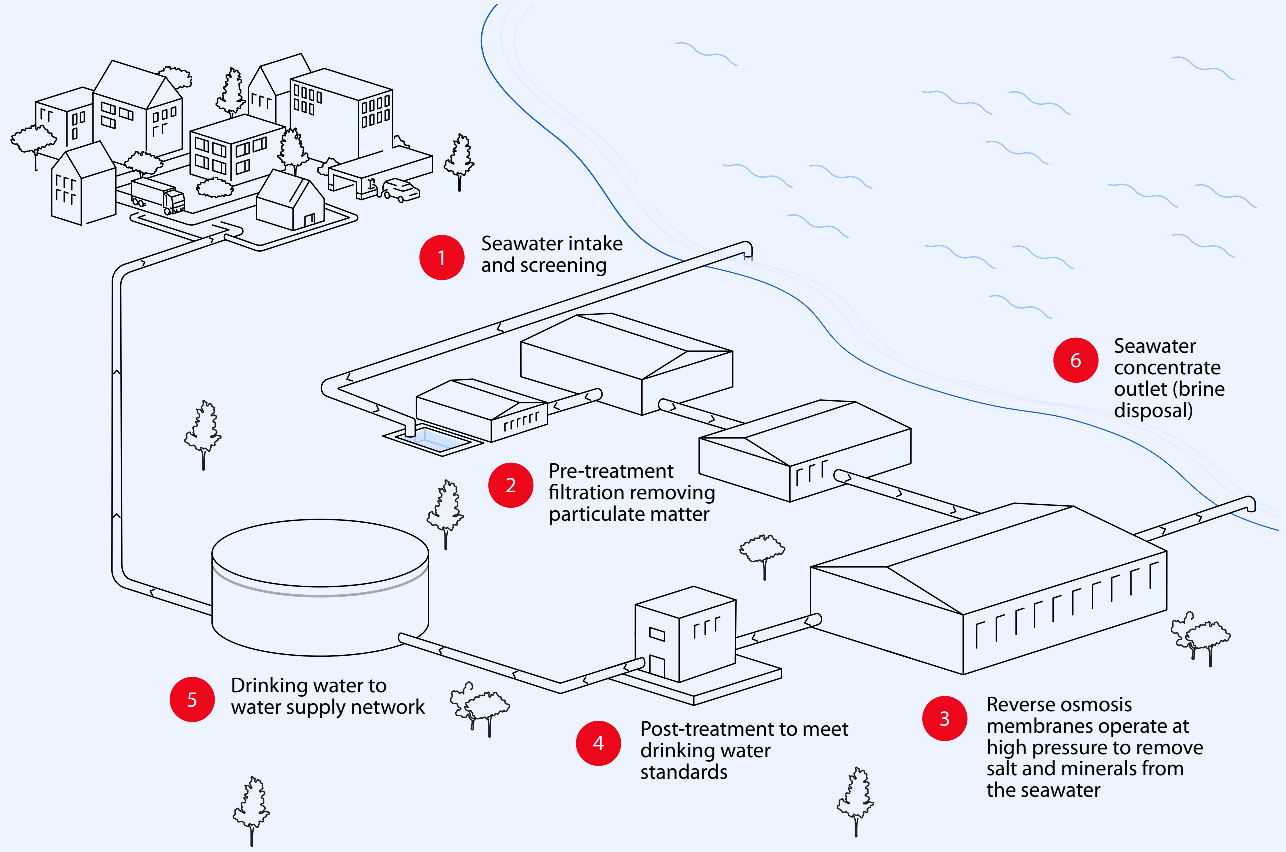
Freshwater is withdrawn from groundwater or surface waters like lakes and rivers. Globally, this water is withdrawn by agriculture (72%), industries (15%), and municipalities (13%).[35] At the same time, freshwater use is increasing globally, which means that energy consumption for withdrawal is increasing and our freshwater reservoirs are facing more stress. Since 1900, global freshwater use has increased six-fold,[36] and by 2030, the demand could outstrip the supply by 40% globally.[37] Already today, **3.6 billion people don't have adequate water access at least one month per year.**[38] On top of this, pesticides and fertilizers from agriculture, untreated human wastewater, and industrial waste are contaminating our water reservoirs. In 2023, 45.5% of global rivers, lakes, and groundwater reservoirs were not of good quality.[39] This all highlights the importance of withdrawing freshwater in a responsible and efficient manner.

Withdrawing water is energy intensive, but there is substantial potential to optimize the processes. For example, groundwater pumping accounts for 89% of energy consumption in irrigated agriculture, despite only 40% of irrigation water being from groundwater. Groundwater pumping for irrigated agriculture consumes 469 TWh and emits 192 million tons of CO_2, or about 13% of the total emissions and energy consumption in agricultural operations.[40] The pumps are driven by a motor, which by default only has two settings: full speed or off. Oftentimes, the motor does not need to run at full speed, and a variable speed drive (VSD) can slow down the speed of a motor to meet the demand and save significant amounts of energy. VSDs have short payback times — often less than two years[41] — and can bring energy savings between 20% and 50% for motors driving water pumps.[42] VSDs also ensure that the right amount of water is used — no more no less. This means less pull on the scarce freshwater resources.

Replacing older VSDs can also lead to energy reductions. A case in point is the Chertsey Water Works in the UK, where older VSDs were replaced with newer models to optimize the operation of pumps. This resulted in energy savings of over 168,000 kWh per year, reducing CO_2 emissions by 1,776 tons over the drives' lifecycle and saving the utility over £300,000 in electricity costs.[43] This example demonstrates how existing water infrastructure can be made significantly more efficient by applying modern drive technology.

When it is not possible to withdraw water responsibly and efficiently, it is necessary to produce water through modern processes to meet the water demand. Despite technological advances, these processes are highly energy intensive, and choosing the right technologies will make it or break it for our energy system. One of the most promising ways is producing freshwater from saltwater through desalination.

Figure 5
How a desalination plant works[44]

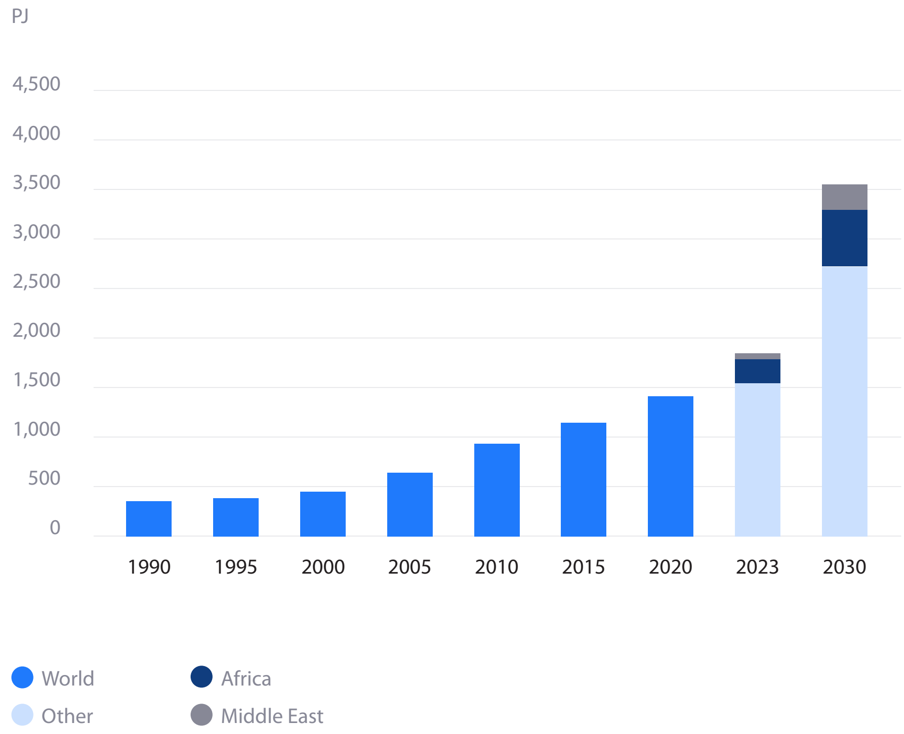


Desalination

Addressing water scarcity will require that many geographies resort to more energy-intensive forms of water production, such as desalination. In regions facing water stress, desalination is already applied as a solution. In the Middle East, responsible for 48% of global desalination capacity,[45] desalination accounted for 7% of total final energy consumption in 2024.[46] By 2050, this number is expected to more than double to 15%.[47] Nonetheless, freshwater production through desalination is already necessary in many regions around the world. For example, while the technology has been widely adopted in Spain and Greece for years, even countries like Italy and the UK are expanding their desalination capacity to meet their freshwater needs. As such, focusing on energy efficiency in the process is key to reducing its environmental and economic impact.

In recent decades, desalination has become very efficient[48], but it is still an energy-intensive way to

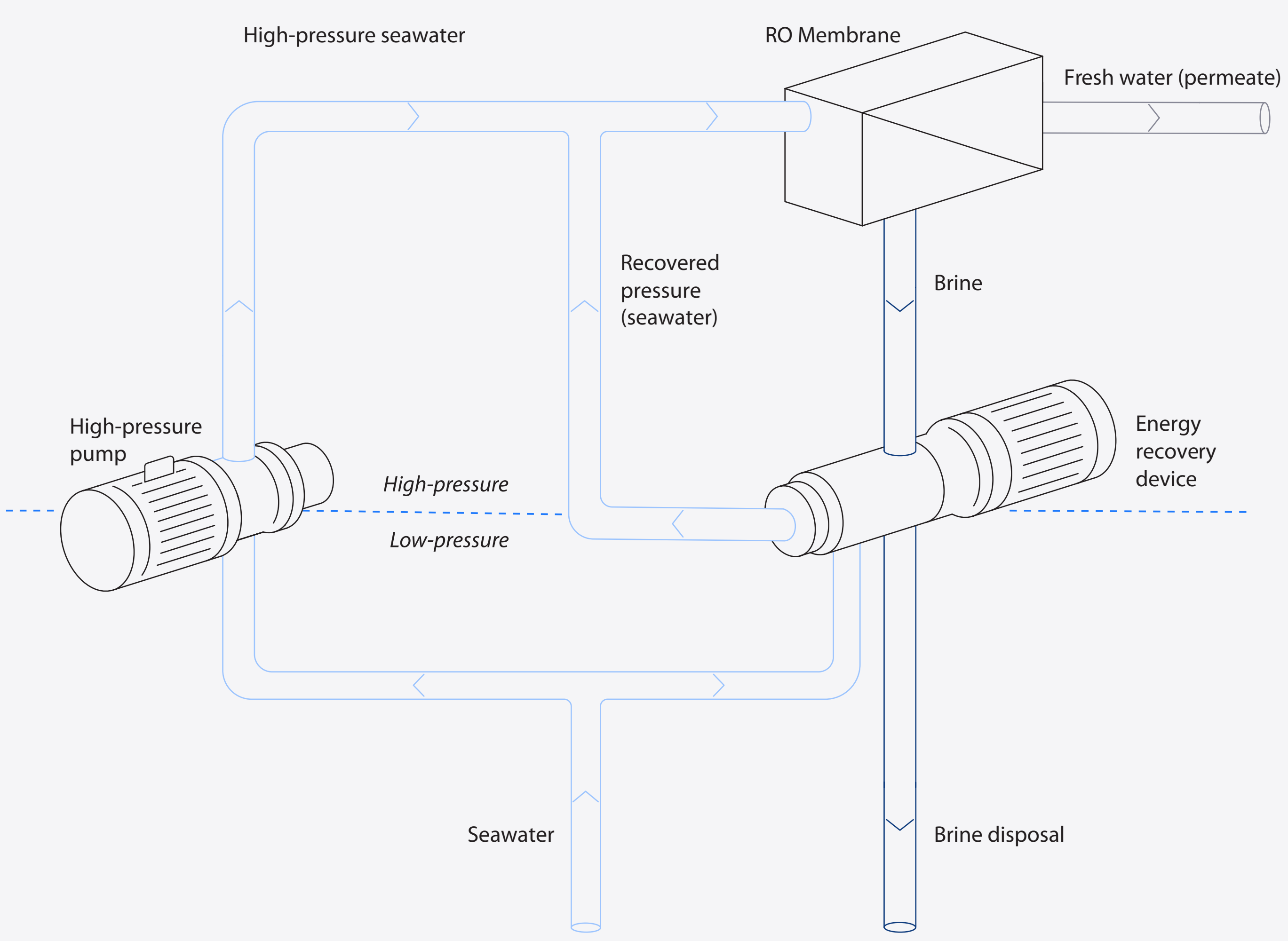
Figure 6
IEA: Energy demand growth for desalination by region[50]



meet the water demand. Therefore, before resorting to desalination to ensure a stable water supply, it is important to reduce water losses in the distribution system locally and reduce end-use water consumption. You can read more about this on p. 24 and p. 28, respectively. However, even after these steps have been taken, there will inevitably be a large demand for producing water through desalination. The International Energy Agency (IEA) has projected that the global energy demand for desalination will double from 562 TWh in 2023 to 1,079 TWh in 2030 (Figure 6).[49] This growth is primarily driven by the Middle East and Africa. The Middle East will represent more than three quarters of global desalination energy consumption by 2030. Choosing the most efficient solution is therefore crucial both for local water and energy security, and by far the most efficient technology to produce freshwater from seawater is seawater reverse osmosis (SWRO).

While desalination shouldn't be the first option to provide enough drinking water, it is the most reliable and widely deployed of the unconventional methods.[51] Today, SWRO provides clean and safe drinking water that can be the solution in regions and cities that face water scarcity. Bottled water often becomes the preferred choice, but this water certainly comes with a footprint.[52] Transportation of bottled water alone oftentimes consumes hundreds of times more energy than producing water through SWRO.[53] With the rise of smaller, more modular and flexible desalination systems, water can be produced, bottled, and distributed locally, which in turn will limit the demand for transportation of bottled water. Another benefit of these modular systems is that they can be containerized and shipped to locations with sudden water scarcity issues, for example due to droughts.

Figure 7
Seawater reverse osmosis



How seawater reverse osmosis works

In seawater reverse osmosis, the high-pressure loop is the most critical yet energy-intensive stage. Seawater is extracted and fed into a high-pressure pump, which pushes the water through a reverse osmosis membrane, filtering out salt and other contaminants in the process. Freshwater is collected, while an energy recovery device (ERD) harvests remaining pressure in the brine, feeding it back into the pressure loop to reduce demand on the high-pressure pump, thereby saving energy. Brine is then transported far from the coast into areas with high circulation and flow of seawater to ensure it is sufficiently mixed and dispersed.

Efficiency in desalination

Retrofitting legacy desalination plants can lead to significant savings. However, despite the striking efficiency improvements in SWRO in recent years, there are many legacy desalination plants that still run at low efficiency. Over the lifetime of a typical desalination plant, 75% of its running cost covers operations (OPEX). In particular, the high-pressure loop (see Figure 7) requires large amounts of energy. While equipment for the high-pressure loop only accounts for 5% of the investments, the loop accounts for 45% of the operational costs.[54]

With technology that already exists today, it is possible for SWRO plants to achieve an efficiency of below 2 kWh/m^3 (see case "World record in seawater reverse osmosis energy efficiency" on p. 20). While this is still energy intensive compared to groundwater withdrawal, it is an immense step forward in the energy efficiency of desalination. In particular, within the high-pressure loop, **improvements in energy recovery and high-pressure pumping have some of the greatest untapped potential to achieve significant energy savings.**

An energy recovery device essentially captures the pressure in the rejected material that does not pass the reverse osmosis membrane, and passes this pressure on to the next loop, so this pressure does not have to be recreated (see Figure 7). For a relatively small upfront investment, SWRO plant operators typically save up to 60% of total energy costs by including energy recovery devices in their designs. Although energy recovery devices have become increasingly common over the last 15 years, there are still many SWRO plants that operate without them.[55]

Similarly, high-pressure pumps used in SWRO represent 80% of all electrical energy costs — or over a third of total operational costs. Opting for the most energy-efficient high-pressure pumps available can also make a significant difference in the long run. In many cases, and whenever feasible, high-pressure pumps can reduce overall energy costs by 20-30% compared to conventional pumps, achieving a relatively quick payback time on the incrementally higher initial investment.[56]

But if retrofitting is such a good idea, why don't more plant owners and operators do it? Given the striking potential of retrofits to save energy, one would think that all desalination plant owners with older technology would already have switched out their old technology for the latest, best-in-class alternatives. Indeed, many have, and even more will do so in the future. Still, many continue to wait.

Why? Poor awareness of the benefits of retrofitting, reluctance to be an early adopter of new technology, and the inertia of not fixing what hasn't broken all matter. But the biggest reasons are upfront investments (CAPEX) and hesitation regarding payback times. For some plant owners, access to the capital required to retrofit their plant is problematic. For others, a payback time of anything more than a year raises doubts — even though they could save energy, money, and CO_2 over a longer time horizon. However, **relatively small CAPEX investments can have an outsized impact on OPEX and total cost of ownership** (TCO). Still, not all desalination investment decisions are made with a TCO mindset.

Desalination as a flexibility lever

While still highly energy intensive, modern SWRO technologies have taken major leaps in efficiency. That said, they can actually also overproduce, meaning they can produce more water, but with slightly higher energy consumption per cubic meter of water. This means that when there is a surplus of electricity in the system — for instance when the sun is shining and the wind is blowing — this electricity can be used to produce water. However, what is happening today is that renewable electricity producers are being paid to shut down production when there is too much electricity in the grid — also known as curtailment. Although overproducing water might use more electricity per cubic meter, it will benefit us all by ensuring that the electricity is actually used and that money is saved in the form of avoided curtailment costs.

Overproducing water at the right time can be one of many demand-side flexibility levers which will be key in the electric transition, and at the same time, storing water is both simple and cheap. Actually, demand-side flexibility is recognized as a cornerstone in the EU's Action Plan for Affordable Energy, and it is estimated that demand-side flexibility can reduce electricity bills by up to 42% and deliver up to EUR 29 billion in societal savings.[57]

Case story

World record in seawater reverse osmosis energy efficiency

Today, the water sector accounts for 4% of global electricity consumption,[58] including for desalination. Producing water through desalination is energy intensive, but is the best solution when water is scarce. This means that wherever water access is an issue, the energy system must also be considered. As such, a focus on the long-term energy efficiency of any desalination installation must be prioritized.

That is exactly the thinking at the Canary Islands Institute of Technology (ITC), where in 2024 the experimental DESALRO 2.0 desalination plant set a new world record for energy efficiency in seawater reverse osmosis (SWRO). Using a modular, high-pressure seawater desalination system, the institute for the first time ever broke the specific energy consumption barrier of 2.0 kWh/m³ of water produced with a consumption of 1.86 kWh/m³. In real terms, this means that the installation consumed up to 25% less energy than the conventional design of similar desalination plants.[59]

The success of DESALRO 2.0 marks a significant step forward in making SWRO more energy efficient. **In fact, if all existing desalination plants worldwide were retrofitted to operate at 2.0 kWh/m³, the potential savings would be enormous:**[60]

- **Energy savings:** 247 TWh, equivalent to Spain's total electricity usage in 2020
- **Financial savings:** EUR 34.5 billion, enough to build seven wind farms the size of Hornsea 1, one of the largest offshore wind farms in the world.
- **Carbon emissions savings:** 111 million tons of CO_2, equivalent to 20% of emissions from international aviation.[61]

What does this potential look like when applied to existing SWRO infrastructure in specific countries? Let's look at the cases of Spain and Cyprus.

In Spain, the current capacity to produce water through SWRO is 1.3 billion cubic meters annually.[62] This is 78% of the total capacity in Europe, and it consumes as much as 3,514 GWh of electricity per year.[63] Many of the SWRO plants are legacy plants that are highly inefficient. However, as we've seen, retrofitting SWRO can reduce energy consumption to 2.0 kWh/m³, a potential that applies to all legacy plants. Retrofitting SWRO plants can cut 966 GWh per year, which is more than a quarter of the electricity consumption for SWRO in Spain. Plant operators can reduce their electricity bill by a cumulative EUR 165 million[64] while reducing the electricity-related emissions by 152,654 tons of CO_2e.[65]

This doesn't only benefit a plant operator's wallet; Spain is facing challenges with grid congestion and is paying high curtailment costs.[66] This means that Spain must both ramp up renewable energy production and build out the grid to handle the future electricity demand. However, as part of adopting a more holistic approach to the energy transition, investing in energy efficiency in SWRO plants decreases the need for further grid expansion and build-out of renewable energy infrastructure. In other words, by reaching the full potential of retrofitting existing SWRO facilities, Spain can save EUR 15.5 million in build-out of new grid,[67] money that can be redirected into financing the green transition.

Another example is Cyprus. While only inhabiting 0.2% of the EU's population,[68] the small island country accounts for 7.2% of the EU's SWRO capacity. When producing at full capacity, SWRO consumes 343 GWh of electricity per year,[69] equivalent to 6.4% of Cyprus' electricity production.[70] But many of the plants are old and inefficient. By retrofitting these, 107 GWh can be saved. This is as much as 2% of the electricity production.[71] And because 80% of Cyprus' electricity is produced through oil,[72] retrofitting SWRO can be a significant contribution to the phase out of fossil fuels.

Overcoming production barriers

Water production is the most energy-intensive phase of the water cycle. In particular, desalination requires major investments to reach efficiency levels that actually enable it to be a sustainable, long-term solution to meet the ever-growing demand for freshwater. To spark these investments, policies must address the following barriers:

1 Producing water is energy intensive but necessary to address scarcity

With increasing water scarcity, freshwater abstraction — the standard way of accessing freshwater — is under pressure. This requires regions hit particularly hard by water scarcity to explore new avenues for water production, such as desalination, which is highly energy intensive. **To solve this,** policies must set Minimum Efficiency Performance Standards (MEPS) for water production sites. While the impact may not be felt immediately, it can become very powerful in the long term if energy savings justify such requirements. Similarly, prioritizing and incentivizing the adoption of ISO-compliant components for pump systems can ensure manufacturing quality, safety, and environmental responsibility — particularly relevant in public procurement processes. Finally, sustainability ratings and energy labels can help to drive change through demand rather than creating further regulation in the market.

2 Short-term contracts for operation of desalination plants disincentivize energy-efficiency investments

Most desalination plants aren't owned and operated by the same entity. Instead, they're frequently run on short-term contracts, which give little incentive to operators to invest in energy efficiency improvements. This is because, in some cases, payback times may extend beyond the contract period itself. **To solve this,** the costs of energy efficiency improvements should be shared between operators and owners. Based on efficiency ratings, owners of desalination plants with low efficiency ratings should bear a greater share of operating costs, incentivizing both longer-term contracts and greater investment in energy efficiency.

3 There is a misconception around the environmental impact of modern desalination plants

In the past, when desalination was mainly done in thermal plants, brine discharge contained high salinity levels (see Barrier #4), higher concentrations of heavy metals, and elevated temperatures. This has led to a sustained belief amongst the public that desalination is by definition bad for the environment. However, seawater reverse osmosis does not alter the temperature of the water, and it effectively filters many non-natural elements from the water.[73] **To solve this,** effective information campaigns are needed to educate the public and regulators on positive developments in the environmental impact of desalination.

4 In most countries, weak regulation does not require responsible brine discharge

While most water quality regulation targeting brine discharge addresses salinity levels in the concentrated brine itself, it fails to recognize the potential increase in salinity levels that brine could cause in the environment into which it is discharged.[74] **To solve this,** regulation must incentivize best-practice brine discharge, such as transporting it far from the coast into areas with high circulation and flow of seawater to ensure it is sufficiently mixed and dispersed. This could include conducting environmental assessments to understand the best locations for discharge.

Phase 2

Distribution

The second phase of the water-energy nexus is distributing water from producers to users. Moving water requires energy, and it is oftentimes distributed with inefficient equipment in inefficient infrastructure where both energy and water losses occur. Reducing waste can help to give an accurate picture of what the real water demand truly is.

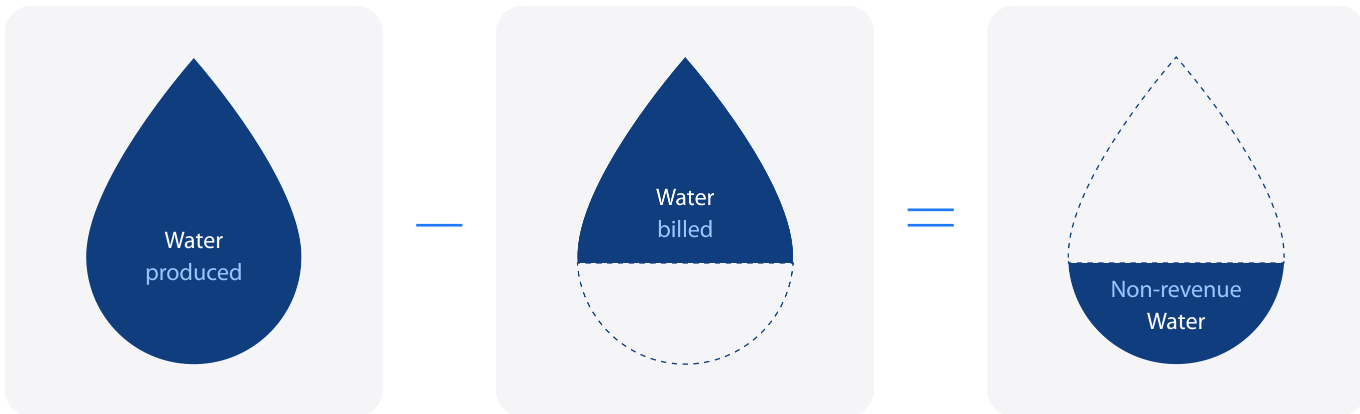
This section introduces challenges with today's water distribution networks — not least the rampant levels of non-revenue water currently experienced in nearly all regions of the world. It then proposes solutions to reduce water and energy waste, including efficient network pressure management and digital solutions for better metering and leak detection.

Non-revenue water

Every day, millions of liters of water around the globe are extracted, produced, treated, and distributed to users — private and commercial. In many countries, between 30% and 60% of this clean and treated water is lost in the distribution to the consumer without being billed.[75] This is called non-revenue water. Some of these losses happen due to poor metering, billing errors, or even water theft. There is even a small proportion of non-revenue water that is intentional, such as water for fighting fires. A large part of it, however, happens because of preventable leakages in the distribution network.

Rates of non-revenue water vary greatly across the globe, in large part due to the old age of distribution infrastructure. Global estimates place the volume of non-revenue water at 126 billion cubic meters per year. This level of non-revenue water amounts to a financial value of $39 billion.[76] If the global non-revenue water were to be reduced by even one-third, the water saved would be enough to supply 800 million people with water.[77] Reducing non-revenue water is possible with the technologies we have today, and doing so will benefit local governments, utility companies, citizens, and the environment.

Figure 8
Non-revenue water is any water that is produced but lost or incorrectly metered before reaching the user



Smart pressure management can cut water leakage by 38%, lower pressure levels by 37%, and reduce pipe breaks by 53%

Addressing non-revenue water

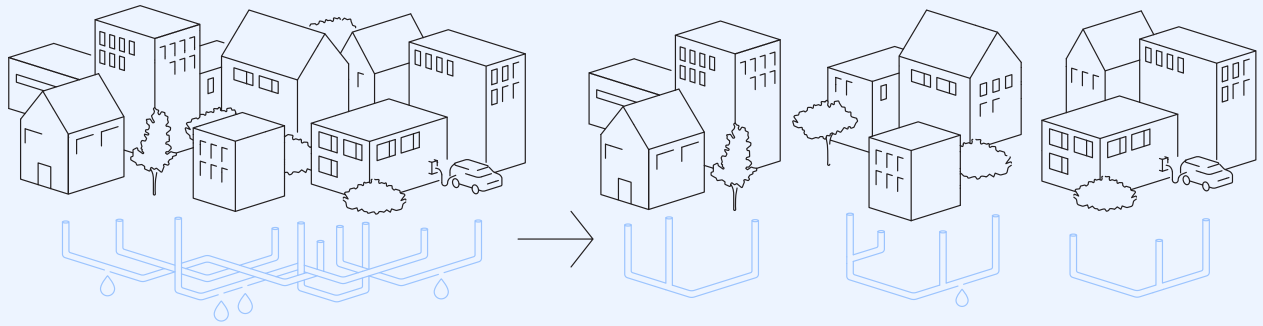
Non-revenue water leads to substantial financial losses for utility companies, which in turn makes it difficult for them to invest in infrastructure upgrades, repairs, and expansions. This problem is especially problematic in urban areas with population growth and aging infrastructure. It hampers urban development and reduces livability and sustainability. Non-revenue water also leads to considerable energy inefficiencies, as more water has to be pumped and treated.[78]

This also means that societies are missing out on opportunities by failing to reduce non-revenue water. For example, reducing non-revenue water will reduce how much water must be withdrawn from local water resources and will allow more people to be serviced from the same source. Similarly, the consequential damages caused by leakages will be reduced. Finally, from an economic perspective, revenue will increase because water that was previously lost can now reach the consumer.

Tackling non-revenue water isn't a simple task and has historically been quite costly, but technological leaps have made it possible to apply digital solutions throughout the distribution network. This can help detect leaks and reduce energy consumption for pumping water much more cost-effectively than their hardware counterparts. Solutions such as sensors, pumps, and variable speed drives (VSD) can reduce water loss and increase the energy efficiency of water distribution networks (see case "Smart pump controls and monitoring systems bring major energy and leakage reductions"). On top of this, the digitalization of these solutions allows for real-time monitoring, which makes it possible to detect and stop leaks much faster.[79]

All of this can be done today and will bring both societal and economic benefits. For example, it will allow municipalities to recover costs incurred in treating and pumping. **A medium-sized city that produces 450,000 cubic meters per day but which loses 25% of the water as non-revenue water is incurring over USD 13 million per year in non-recoverable labor, chemical, and energy expenses.**[80]

In another example from Chile, two water utilities implemented Internet-of-Things (IoT) software solutions to reduce non-revenue water. They reduced real losses, such as those caused by leakages, by 13 million cubic meters per year, and apparent losses, which can be caused by poor metering or theft, by 3.1 million cubic meters of water per year. In total, **non-revenue water was reduced by 8%, leading to EUR 5.8 million savings over three years.**[81]



Case story

Smart pump controls and monitoring systems bring major energy and leakage reductions

In many countries, more than 30% of treated water is lost before reaching consumers.[82] These losses aren't just wasteful — they drive up energy bills, raise operational costs, and put additional stress on already stretched water supplies.

One major culprit is uncontrolled water pressure. Just like over-inflating a balloon makes it more likely to burst, excessive pressure in a pipe increases the chance of leaks, especially in older or more fragile networks. Pressure surges can strain infrastructure and accelerate wear over time. Smart pressure management helps keep pressure levels stable and matched to local needs. By dividing the network into pressure zones, utilities can tailor water pressure more precisely. This reduces leakage and unnecessary energy use related to the loss of water.[83] In fact, this approach can reduce water leakage by 38%, pressure by 37%, and the incidents of pipes breaking by 53%, extending the lifetime of the infrastructure significantly.[84]

Modern technologies make this easier than ever. Digital sensors and centralized monitoring systems provide real-time visibility into network conditions. Variable pump controls, powered by variable speed drives (VSDs), can adjust the pressure based on actual demand — similar to how a thermostat regulates room temperature by only using as much heating or cooling as needed. This soft and adaptive control also helps prevent sudden pressure surges. These pressure shocks can crack pipes, loosen joints, or damage valves, which contributes to costly leaks and water losses. By adjusting pump speed gradually, VSDs help protect infrastructure and reduce maintenance needs, while still optimizing energy use.

The results are clear. In Upper Silesia, Poland, the introduction of pressure zones and digital leak detection reduced energy consumption by 12% in just one year.[85] In northern Iran, a system serving over 44,000 people achieved a 41.7% reduction in leakage and a 28.4% drop in power consumption by continuously adjusting pump output to match real-time conditions.[86] Even relatively simple upgrades can deliver significant savings. With digital tools and smart pump control, utilities can reduce both water and energy losses.

In many countries, more than 30% of treated water is lost before reaching consumers, resulting in both water and energy losses.

Overcoming distribution barriers

Water distribution networks are among the most outdated parts of the water system. Infrastructure is leaky and aging, causing water losses that impact both up- and downstream phases of the water cycle. Poor pressure management leads to even greater water losses, while also increasing the energy used to move the water to the consumer. Pressure spikes due to leakages or sudden increases in consumption lead to the need for costly repairs and increased energy costs.

1 Investment in tackling non-revenue water

Global estimates place the volume of non-revenue water at 126 billion cubic meters per year. This level of non-revenue water carries a financial value of roughly $39 billion and puts significant strain on water production and distribution infrastructure. It also poses a humanitarian risk: if the global non-revenue water were to be reduced by even one-third, the water saved would be enough to supply 800 million people with water.[87] **To solve this,** cities and utilities must employ existing technologies to better manage pressure control. This will reduce wear on pipes and system hardware. Similarly, modernizing networks with digital solutions will enable utility operators to gather real-time data on network conditions (see Barriers #2 and #3 for more).

2 Improper pressure control in water distribution networks

Networks and infrastructure in poor condition will need increased pressure to provide the water needed at consumer level, yet the control of that pressure needs to be constantly adapted to the current need. **To solve this,** technologies, such as variable speed drives and smart sensing solutions, can adapt pressure to meet the exact need, ensuring lower wear and tear on infrastructure and no unnecessarily high pressure in the network, which comes at great energy costs. However, overcoming the investment costs requires a policy environment that incentivizes the adoption of water- and energy-efficient technologies.

3 Lack of data on water distribution networks

Being able to adapt water pressure to meet exact needs requires real-time data. The low degree of digitalization in the sector means there's little access to data that can spark great energy, water, and cost savings. **To solve this,** it's critical to promote digitalization of water distribution networks through awareness and incentives. In particular, focus is needed on advanced pressure management and leak detection to minimize and rapidly identify leaks, minimizing non-revenue water and related energy costs. Increasing digitalization and data availability further allows for localizing inefficiencies down to basin level and can lead to more innovation within the field.

Phase 3

Consumption

Water is consumed across every sector of society and is necessary to produce crops, clothes, cars, and to sustain life itself. However, despite increasing levels of water scarcity and insecurity, water demand continues to grow as populations grow and as new industrial uses emerge. The first and most important step in reducing water scarcity is to reduce consumption of water wherever possible.

This section identifies several energy-intensive sectors and end uses where there is great potential to reduce water consumption. In particular, it focuses on challenges and solutions to lower demand for water and energy within agriculture, industry, and data centers.

Agriculture

Agriculture is the world's largest water-consuming sector, accounting for approximately 72% of global freshwater withdrawals.[88] Yet, despite its vital role in food and resource production, agricultural water use is often suboptimal. In fact, World Wildlife Fund (WWF) estimates that some 60% of agricultural water consumption is wasted, in part because of leaky irrigation systems and inefficient application systems.[89] On top of this, more than half of the irrigation expansion in this century has taken place in areas that were already water-stressed at the start of the century.[90] Additionally, it has been estimated that water consumption for irrigation will still have to increase by 146% by the middle of the 21st century.[91] The growing water demand for irrigation is an immense challenge, and there is not a simple solution to it. Rather, the challenge must be faced by many approaches. For example, while irrigation can be greatly reduced through methods such as strategic crop selection and land use design, technological solutions can also reduce water consumption significantly. Innovative methods and technologies exist to lower waste and costs by optimizing both water and energy usage.

Efficient irrigation for water and energy savings

Irrigation is an energy-intensive process because water has to be moved from a source such as wells or rivers and distributed over a large area of crops. Although irrigation almost always requires a lot of energy, the efficiency of the technology used in many cases could be greatly improved. For example, one study estimated that by improving irrigation methods and utilizing better technology, water consumption could be reduced by up to 68% globally compared to traditional irrigation methods.[92]

Additionally, upgrading irrigation systems with more efficient technologies such as variable speed drives (VSD), smart sensors, and electric pumps can significantly reduce the energy required for irrigation. There have been multiple cases where VSDs alone have reduced irrigation-related energy consumption by half, depending on operating conditions.[93, 94]

Modern methods of irrigation are more water-efficient because they target the roots directly in a controlled manner, minimizing water loss that otherwise occurs through evaporation and runoff. Imagine the difference between watering your garden with a hose on full blast (i.e., surface irrigation), versus using a slow-drip watering tool directly at the base of each plant (i.e., drip irrigation).

Beyond irrigation methods, there is also significant untapped potential in upgrading irrigation technologies. Globally, 74% of energy used in groundwater pumping for irrigation comes from diesel-powered pumps, while only 26% derives from electric pumps. Diesel-powered pumps typically consume more than twice as much energy as electric pumps, and replacing diesel-powered pumps with new, more efficient electrified pumps could cut energy consumption by 51%, translating into substantial cost savings and emissions reductions.[95] In more remote areas with limited grid access, transitioning to electric pumps may not yet be viable, but ongoing advances in infrastructure and technology are improving the feasibility of electrification in agriculture. In such cases, off-grid solutions, such as battery-supported irrigation systems,

Water demand for industry and energy is projected to grow to 24% by 2050, driven by expanding manufacturing and technology sectors.

may play a key role in supporting the shift towards greater electrification. At the end of the day, the feasibility of any given solution will depend upon the local context and geographic location.

Indeed, there are substantial efficiency gains and emissions reductions to be achieved already today just by implementing existing and proven irrigation methods and technologies.

Industry

Globally, industry accounts for around 15% of all freshwater withdrawals.[96] Additionally, water demand for industry and energy is projected to grow to 24% by 2050,[97] driven by expanding manufacturing and technology sectors. In all its forms, water is a cornerstone of industrial production. Whether used for cooling, washing, diluting, processing, transporting, or integrating into products, water is fundamental to nearly every step of industrial activity. Much like energy, water is a key resource that keeps industry running. But in today's landscape, industry can no longer take water for granted.

Due to rising costs of energy and water, industry is being forced to rethink how water is sourced, used, and reused across their operations. For industries operating in water-scarce regions, the risks are even greater. By sometime between 2030 and 2040, 40% of global semiconductor manufacturing sites will be in regions facing high or extreme water stress.[98] Semiconductors are important in e-mobility, renewables, and many other industries that are essential to the green transition. However, they are also highly water intensive to produce. This is a risky overlap between heavy water demand and growing water scarcity that could put industrial resilience at risk.

Other water-intensive industries also face mounting operational risks, such as food and beverage production. For example, producing one kilogram of cereals requires 1,644 liters of water, while eggs require 3,265 liters. Even more water intensive is meat production, with pork (5,988 liters), sheep/goat (8,763 liters), and beef (15,415 liters) topping the list alongside nuts (9,063).[99] While much of this water footprint stems from crop production for livestock feed, there is also considerable water used in food processing itself. In production facilities, water is used for processes such as cleaning, heating, and cooking — all of which require energy for pumping, spraying, boiling, and more.

The same is true in beverage production, where it generally takes 4-6 liters of water to produce one liter of beer.[100] However, even when brewing at industrial scale, strategic deployment of water-efficient equipment and water management techniques can nearly cut this in half (see case "Carlsberg Poland takes holistic approach to reducing water intensity").

Whether producing semiconductors, beef, or beer, the industrial sector employs many energy- and water-intensive processes, which can be optimized through more energy-efficient solutions. As seen in the case from Carlsberg Poland on page 31, this is especially true not only when individual component efficiency is considered but also when overall system efficiency is prioritized.

Case story

Carlsberg Poland takes holistic approach to reducing water intensity

Producing beverages is a water intensive process, and at Carlsberg Poland they are taking impressive steps to reduce the amount of water it takes to produce a beer. Carlsberg Poland is reducing their water consumption through a systemic approach as a part of their ESG focus area "Zero Water Waste".

At all four facilities in Poland, Carlsberg is increasingly recovering and reusing water, investing in water-efficient equipment, increasingly monitoring water consumption to identify savings opportunities and detect leaks, improving the water habits of the staff, setting measurable targets, and including water activities in the bonus targets of selected employees.

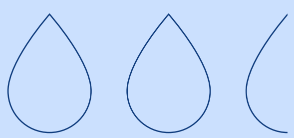
All these steps together have improved the water efficiency in Carlsberg Poland's productions. Since 2015, they have managed to decrease their relative water consumption by 17%. As a result, it now takes Carlsberg Poland only 2.55 liters of water to produce one liter of beer.[101] This is significantly better than the market standards, where it typically takes between 4-6 liters of water to produce one liter of beer.[102] By further improving these processes, the company aims to further lower the water to beer ratio to 2:1 by 2030.

Water efficiency in beer production

Carlsberg Poland

2.55 L

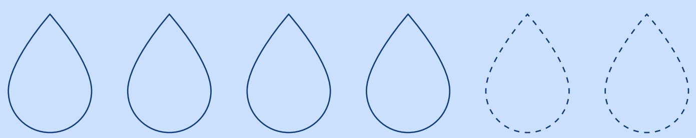
of water to produce one liter of beer



Market standard

4-6 L

of water to produce one liter of beer



Data Centers

The increasing energy demand of data centers receives much attention in the debate around the rise of AI and digital technologies, and for good reason: global energy demand for data centers is set to double by 2030. However, what is less often discussed is the water footprint of data centers. Some data centers have a very high level of water consumption, both directly for cooling its servers and indirectly through their high consumption of fossil fuel-generated electricity, which itself requires vast amounts of water for cooling. Globally, data centers consume 560 billion liters per year, and this could rise to 1,200 billion in 2030.[103] That's six times the EU's total freshwater abstraction in 2022.[104] Increasing the cooling efficiency of data centers is essential for driving down both energy and water consumption.

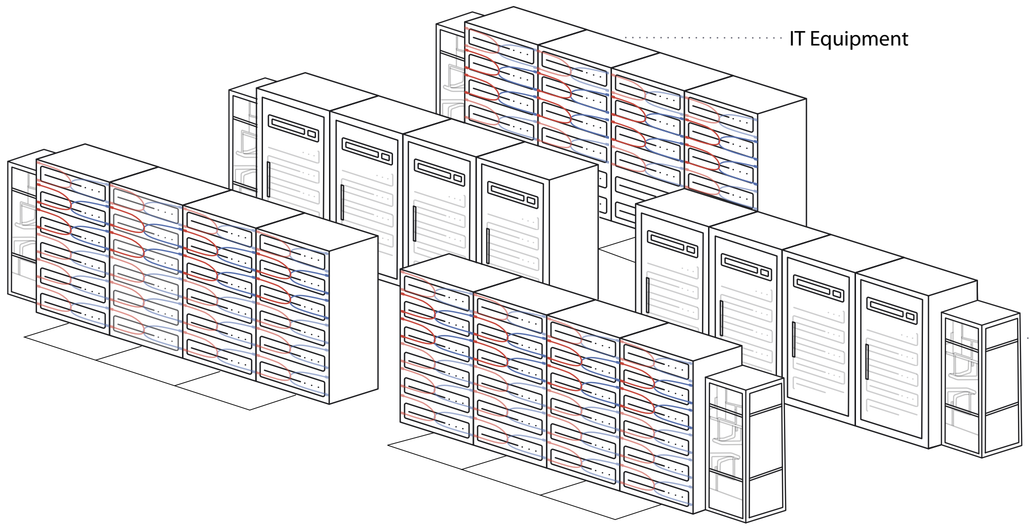
Reducing water and energy demand for data center cooling

Historically, data centers have broadly relied on systems that cool servers using air — either through dry air cooling or evaporative cooling.[105] Both cooling technologies have long been effective in ensuring optimal operational temperatures for chips and servers. However, as data demand becomes greater and more complex due to increased adoption of AI, machine learning, and internet services, the chips powering these services have become significantly more powerful, and therefore increasingly heat-intensive. In simpler terms, each server now generates much more heat, packed into roughly the same physical space. This rise in power density is pushing traditional air-based cooling methods to their limits. The challenge is particularly acute for evaporative cooling, which relies on large volumes of water.

As a result, many operators are now turning to more efficient and water-saving technologies, such as direct-to-chip liquid cooling, which operates on a closed water loop. Not only are these more effective at getting cold water physically closer to the heat source (i.e., the processing units) but **liquid cooling consumes far less water compared to traditional evaporative cooling systems. Direct-to-chip liquid cooling systems are also at least 15% more energy efficient than their air-cooling counterparts.**[106] They also make it easier to recover and reuse the large amounts of waste heat produced by data centers for other purposes (see case "Liquid cooling optimizes data center waste heat reuse" on p. 34).

Other prominent forms of liquid cooling known as 'single-phase' and 'dual-phase' immersion also exist — though they are still in development and are rarely deployed in a commercial setting. These processes involve entirely submerging server racks in non-conductive cooling fluids to maintain operational temperatures. While these methods carry the promise of energy and water efficiency, they come with drawbacks as well — such as high flammability leading to safety concerns, high viscosity that can create pumping difficulties, or the use of highly regulated fluids.

Liquid cooling for data centers is the most efficient and most effective way to meet the rapidly increasing demand for high-density and AI-driven data centers while also minimizing their impact on water and energy systems, and therefore their impact on the climate. Determining which form of liquid cooling is most suitable for a given data center will come down to local resource availability, the regulatory environment, and the cooling capacity needed.

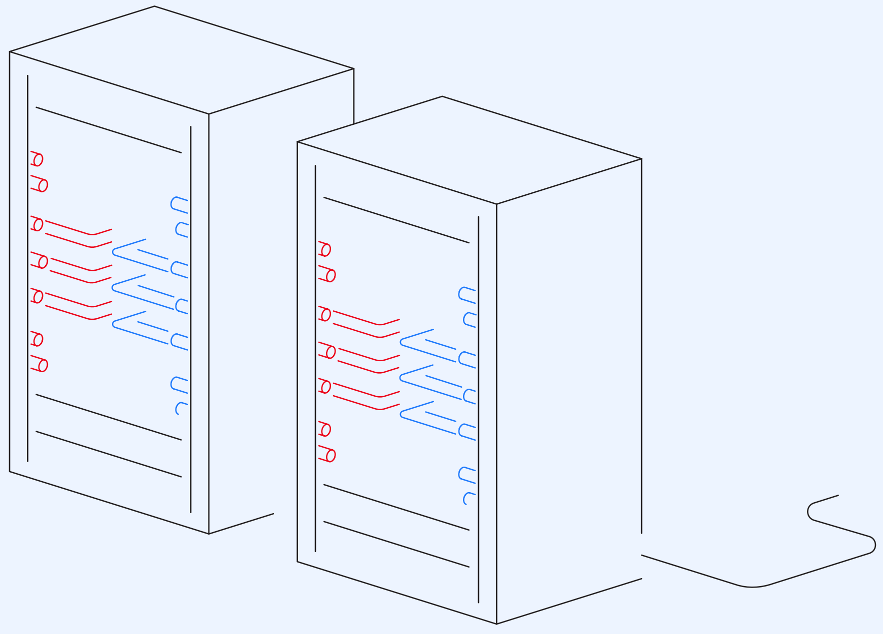


Key terms: Data center efficiency

There are several important metrics for policymakers to understand when evaluating the performance of data centers:

- **Water Use Effectiveness (WUE)** is the ratio between the use of water in data center systems and the energy consumption of the IT equipment. The lower a data center's WUE ratio is, the more efficient its use of water resources is.
- **Power Usage Effectiveness (PUE)** is a ratio that describes how efficiently a computer data center uses energy — specifically, how much energy is used by the computing equipment. PUE is the ratio of the total amount of energy used by a computer data center facility to the energy delivered to computing equipment.
- **Energy Reuse Factor (ERF)** is the ratio of energy being reused (e.g., as captured waste heat) divided by the sum of all energy consumed in a data center. The ERF reflects the efficiency of the reuse process, which is not itself part of a data center.
- **Carbon Usage Effectiveness (CUE)** is a metric developed by The Green Grid to measure data center sustainability in terms of carbon emissions. CUE is the ratio of the total CO_2 emissions caused by total data center energy consumption to the energy consumption of IT equipment.
- **Renewable Energy Factor (REF)** represents the ratio of total renewable energy consumption to total energy consumption. Similar to CUE, this metric helps to understand the carbon intensity of energy input into a data center.

Each of these metrics can be applied to the performance evaluation of a type or actual data center, through modeling or real-time performance evaluation, to help determine both financial costs and ESG impacts (and impact improvements) of a center.



Case story

Liquid cooling optimizes data center waste heat reuse

The increasing excess heat generated by the powerful processing units in modern data centers not only requires operators to adopt innovative cooling methods, but it can also be reused to meet heat demand elsewhere. In fact, according to the International Energy Agency (IEA), **waste heat from data centers can meet 10% of Europe's space heating demand by 2030.**[107]

How does this work? While the largest data centers will be placed too far away from urban areas to meaningfully utilize the waste heat, excess heat from data centers can meet 300 TWh of heat demand for off-takers within a few kilometers distance.[108] For example, one project supported by the UK government will heat 10,000 homes and 250,000m^2 of commercial space with waste heat from nearby data centers.[109] In the future, if decision makers and urban planners plan holistically and strategically, the potential could be much higher.

From a technical perspective, air-cooled systems for data centers traditionally required heat pumps to capture and boost the waste heat to usable temperatures. However, **liquid cooling systems can provide higher temperature heat (+40°C), which after boosting can be directly repurposed in district heating networks.**[110] Liquid cooling captures heat directly from server components using a fluid with far higher thermal conductivity and heat capacity than air, allowing it to leave the data center at much higher temperatures. This eliminates the heat losses and temperature limits of air cooling, making the heat immediately suitable for reuse in low-temperature district heating networks without a heat pump.

This waste heat reuse is not only more efficient, but also more economically sensible. The IEA has reported that waste heat from data centers can supply district heating networks at a cost of EUR 190,000-250,000 per megawatt of heat, compared to more than EUR 730,000 per megawatt of heat from an unabated natural gas combined heat and power plant.[111]

Overcoming consumption barriers

Water demand is driven primarily by two sectors: agriculture and industry. However, the rise of AI and the corresponding data infrastructure pose a new challenge to increasing water and energy demand. These effects are felt above all at the local level.[112] Overcoming barriers in these sectors and end uses will require a blend of modern water- and energy-management techniques, more efficient technologies, and novel methods of water accounting.

1 Water efficiency is underprioritized and far too much is being wasted

Water waste can be found everywhere in the consumption phase, especially in some of the highest consuming sectors, such as agriculture, industry, and data centers. **To solve this,** implementing a Water Efficiency First principle, as is suggested in the EU, will ensure that water efficiency standards are implemented across applications.

2 Water pricing is a complex and contested debate

Water needs to be cheap to ensure easy access to this life-sustaining resource. However, low prices also incentivize overuse, which threatens the resilience of water systems in the long term. **To solve this,** we need greater transparency into the real price of water, which requires more comprehensive data collection. This will demand better digital monitoring systems both at the distribution and consumption level. A clearer view into the real price of water will help to strengthen business cases and map the impact of water consumption on local water networks and resources.

3 AI and data centers can pose a local challenge to water resilience

The expansion of data centers and their high demand for both energy and water is not stopping anytime soon, and the water consumption for data centers can pose local challenges to water resilience. **To solve this,** policymakers must focus on the most water-intensive process of data centers: cooling. The shift to liquid cooling is already underway out of pure technological necessity, but not all forms of liquid cooling are created equally. They vary on measures of energy efficiency, water efficiency, and environmental risks — factors which must be taken into account when creating regulations for the sector. Similarly, for data center operators, conducting life-cycle assessments for existing and future data centers is critical in understanding their long-term impact on resource availability in local communities.

4 Water-saving irrigation methods remain underutilized

Drip and sprinkler irrigation systems can drastically reduce water consumption compared to traditional surface irrigation. Barriers include high upfront investment costs, limited technical capacity for installation, and a lack of economic incentives. Yet despite the investment, these improved systems often have lower operating costs, resulting in a lower total cost of ownership (TCO) over time. **To solve this,** policymakers should consider financial support for farmers investing in water-efficient irrigation, such as subsidies, low-interest loans, or tax incentives. Such mechanisms should prioritize projects with low operational expenditure and TCO.

Phase 4

Treatment & Reuse

The last, or rather first, step in the economic life cycle of water is the treatment and reuse phase. This phase is a transitional phase, giving new value to water by bringing contaminated water back to a level that is ready for distribution and consumption. Treatment and reuse close the water loop — ensuring that water does not become a one-time-use resource, but instead part of a circular, resource-efficient system where water is supplied efficiently.

Within this phase, two areas stand out in terms of energy intensity and potential for impact: wastewater treatment and industrial water reuse. Both represent major opportunities to decarbonize water systems while increasing resource resilience. This section will present challenges and solutions within these two processes.

Wastewater treatment

When water is used, it often becomes polluted — whether from households, industry, or agriculture. Think, for instance, of water flushed from a toilet or drained from a factory. This water must be treated at wastewater treatment plants (WWTPs) before it can be safely released into the environment or reused.

However, wastewater treatment is highly energy intensive. From pumping and aeration to sludge handling and disinfection, each step requires significant energy input. In fact, water and wastewater systems account for approximately 4% of global electricity consumption, with wastewater treatment as a major contributor.[113]

Studies have found that WWTPs can consume between 30–40% of a municipality's total electricity budget. Furthermore, electricity bills are the second largest operational cost for wastewater utilities after labor.[114, 115] These plants are often outdated, running on fixed-speed equipment and limited monitoring systems, resulting in energy waste and process inefficiencies. Modernizing WWTPs is a critical step to strengthening the resilience of the water sector while at the same time reducing its reliance on the energy system.

By digitalizing operations and optimizing process control, wastewater treatment plants can significantly reduce both energy use and operational costs. For example, installing variable speed drives (VSD) enables motors and pumps to adjust to real-time demand rather than running at fixed speeds, improving efficiency across the system. In aeration tanks, where air is pumped into wastewater to support biological breakdown of pollutants, VSDs allow blowers to match the exact oxygen demand of microorganisms, instead of running continuously at full power. Sensor-based monitoring systems play a key role here, providing real-time data that enables automatic adjustment of pump and blower speeds.[116] These improvements not only cut energy consumption but also reduce wear on equipment and extend asset lifetimes, as demonstrated in practice by facilities like the Marselisborg wastewater treatment plant (see case "Digitalizing the Marselisborg Wastewater Treatment Plant").

Achieving energy neutrality in wastewater treatment plants

Wastewater is not just a waste product — it contains significant amounts of embedded energy. With the right technologies, this energy can be systematically recovered. Sludge can be extracted from wastewater and pumped into digesters. These produce biogas, mostly methane, that can then be burned to make heat and electricity. Before the cleaned water is released, it can be cooled down with a heat pump, which extracts waste heat to be supplied to the local district heating network. Consequently, wastewater treatment plants have the potential to be turned from energy consumers to energy producers.

Case story

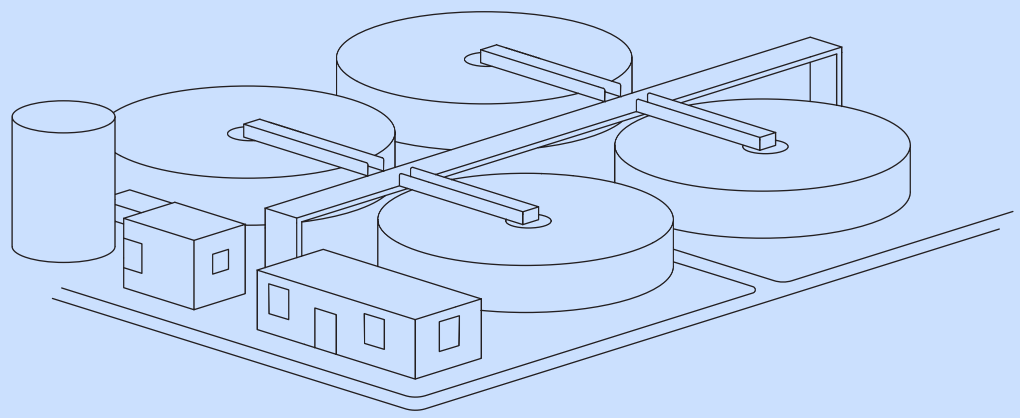
Decoupling WWTP demand growth from electricity consumption in China

Due to rapid urbanization and industrialization, China faces the challenge of having to clean an increasing amount of wastewater. While the country has managed to treat five times more water from 2006 to 2019, it has not managed to decrease the relative electricity consumption of WWTPs in the same period (Figure 9). Additionally, China has ambitions of treating 95% of its wastewater — something they are currently delivering on.[117] If the Chinese WWT sector doesn't break the curve of electricity consumption, this will have a massive pull on the grid. Similarly, as a large proportion of municipalities' energy bills is spent treating wastewater, reducing the energy consumption of WWTPs can save significant amounts of money.

In light of urban and industrial growth, if the development from 2006 to 2019 continues, China will very likely need to treat at least 25% more water by 2035.[118] While WWTPs can cut their electricity consumption by 55% by 2040 by recovering embedded energy in the organic matter,[119] this is not a solution that applies everywhere. For example, in many cities in China, this is not an economically feasible solution because relatively clean rainwater and wastewater share the same pipes, which means that the concentration of organic matter drops significantly. However, one solution that does apply to China — variable speed drives (VSDs) — can bring anything in the range of 20-60% electricity savings. They bring these savings by ensuring that the otherwise highly wasteful motors running the WWTP only deliver the output they need and therefore only use the energy they need. VSDs typically have a payback time of one to five years, dependent largely upon electricity prices.

If China installs VSDs on all new WWTPs while retrofitting existing plants, they can treat 25% more wastewater by 2035 and use 2.5% less in electricity than in 2019. However, if China misses out on this opportunity, the sector will consume 25% more electricity to treat the same amount of water.[120] This is applying conservative savings potentials for VSDs. On top of this there is a significant potential in upgrading the motor. Many motors are old and inefficient, and combining a modern motor with a VSD can truly decouple the growing WWTP demand from electricity consumption.

Figure 9
Wastewater volume and electricity consumption in China from 2006-2019,[121, 122] and projected wastewater volume and electricity consumption by 2035 in a business-as-usual (BAU) scenario and an Energy efficiency through VSDs scenario. In the VSD scenario, the existing WWTPs are retrofitted with VSDs, while all new WWTPs are VSD-enabled from the outset.



Case story

Digitalizing the Marselisborg Wastewater Treatment Plant

In Aarhus, Denmark, the Marselisborg Wastewater Treatment Plant (WWTP), operated by Aarhus Water, has shown how digitalization and energy optimization can turn a conventional utility into an energy-positive system. Between 2016 and 2021, Marselisborg WWTP consistently produced 100% more energy than it consumed to treat wastewater. This energy surplus was sufficient to power the entire water cycle for a city of 200,000 people, including drinking water distribution and wastewater recovery. Through this, the utility effectively decoupled the city's water services from external energy demand.[123]

This achievement was largely driven by strategic digitalization and automation, which accounted for approximately 70% of the overall efficiency improvements. A total of 125 variable speed drives (VSDs) were installed across motor-driven equipment throughout the plant, enabling precise control over energy use in real time. These VSDs were paired with a network of online sensors that continuously provided critical operational data. This infrastructure allowed the plant's control systems to automatically calculate optimal setpoints for equipment, ensuring performance was consistently optimized while minimizing energy waste.[124]

Beyond energy savings, Marselisborg also highlights the potential of wastewater as a source of heat. Waste heat from treated wastewater can be recovered and pumped into district heating networks, potentially supplying 10-15% of the global residential heat demand.[125]

The transformation of Marselisborg WWTP into an energy-producing facility came with a strong economic case: the return on investment was just 4.8 years.[126] If replicated globally, this approach could have a transformative impact. Equipping existing and future wastewater treatment plants with advanced energy optimization technologies could save up to 300 million tons of CO_2e emissions annually by 2030[127] — approximately 10% of the EU's total CO_2e emissions in 2023.[128] Moreover, it would also save an estimated 350 TWh of energy each year,[129] equal to around one-tenth of Germany's energy supply.[130] From a financial perspective, employing energy optimization processes and technologies within the global wastewater treatment sector could provide cost savings of up to EUR 200 billion per year.[131]

Marselisborg WWTP showcases what is possible when digital technologies and energy-efficiency solutions are integrated into critical infrastructure. It demonstrates that wastewater treatment can shift from being an energy burden to becoming a resilient, economically viable asset.

Case story

Turning wastewater into a resource in Chennai, India

In the face of increasing water stress, cities like Chennai, India are under pressure to improve both water security and energy performance in essential infrastructure. At the Koyambedu Wastewater Treatment Plant, one of the largest of its kind in India, this challenge is being met head-on.

The plant treats up to 120 million liters of sewage per day, helping safeguard public health and protect local water bodies.[132] However, like many treatment facilities, it faced high electricity consumption, especially from energy-intensive blowers and pumps required for the biological treatment process.

To tackle this, the plant installed 55 variable speed drives (VSDs) across its operations. These drives enable continuous adjustment of motor speeds, aligning energy use with actual demand. By avoiding overuse and ensuring smooth process control, the solution reduced energy waste and enhanced the reliability of operations.

The result: energy savings of 22% in the plant's cooling and motor control systems, more than USD 700,000 in reduced operating costs over 15 years, and a smaller carbon footprint — all while maintaining the performance needed to serve a growing population.[133]

Industrial water reuse

Across industries, from food and beverage to pharmaceuticals and data centers, water continues to flow in one direction: in, through, and out. Freshwater is withdrawn, used once, and then discharged, often containing pollutants. This is particularly impactful when you consider that industry is the single largest water-withdrawing sector in certain areas of the world, like many European countries, where the sector accounts for over 50% of annual water abstraction.[134]

The potential savings when reducing and reusing water is enormous. If reduce and reuse methods were adopted across all relevant processes in light industries, water use could be reduced by 50–75%. This is equivalent to the annual water consumption of 67 million EU households.[135] These efforts not only conserve water but also reduce the energy required for pumping, heating, and treatment of water — delivering cost savings and emissions reductions. In short, using less water also means spending less money.

Reduce and reuse methods

Optimizing industrial water use requires a dual focus: reducing water consumption and reusing water wherever possible. Reducing industrial water use starts with improving visibility. By monitoring water flows more closely, companies can identify waste and uncover opportunities for efficiency. Sometimes, improvements come from operational adjustments, reducing unnecessary water use by refining internal processes. In other cases, technical improvements such as installing flow meters, automated leak detection, or real-time sensor systems allow water to be used more precisely. These tools help operators monitor water consumption closely, detect

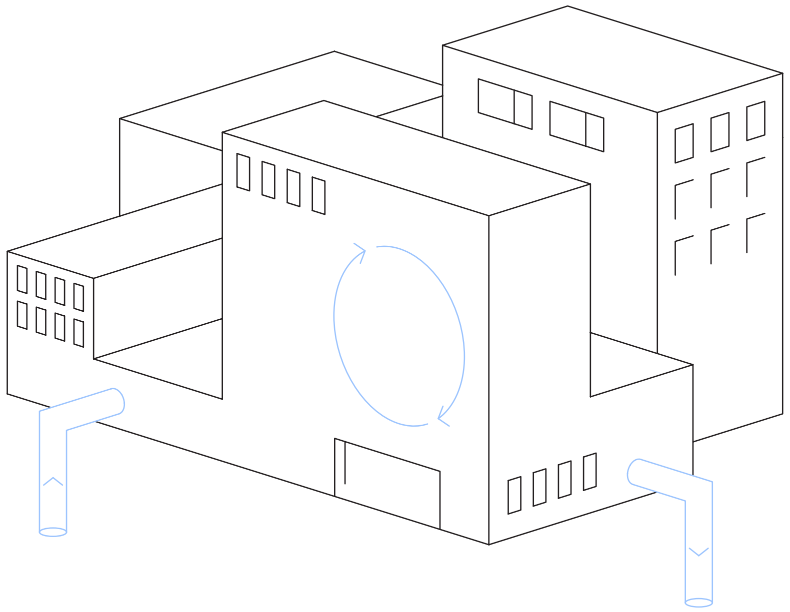
If 'reduce and reuse' methods were adopted across all relevant processes in light industries, water use could be reduced by 50–75%.

inefficiencies, and make adjustments on the fly, reducing waste without compromising performance. Through 'reduce' initiatives alone, **water savings of up to 20-30% within industrial processes can be achieved.**[136]

Reuse refers to the practice of capturing water that has already been used within industrial processes and treating it so it can be used again — often for a different, less sensitive application. Rather than allowing water to exit the facility after a single cycle, companies are installing systems that recirculate water through multiple production stages, particularly for operations such as rinsing, cooling, or cleaning, where quality requirements are moderate. This significantly reduces both freshwater withdrawals and discharge volumes without compromising performance.

The results are already tangible. By applying technologies including membrane filtrations (such as reverse osmosis) and distillation, global cosmetics brand L'Oréal has reduced water consumption in its production processes by 54%, cutting usage from 0.72 to 0.33 liters per finished product between 2005 and 2022.[137] High-pressure pumps ensure efficient membrane performance, while digital tools and sensors provide real-time insights into flow, quality, and system stability.

In many cases, the water being reused does not need to meet drinking water standards — it simply needs to be fit for purpose. This makes industrial reuse not only more sustainable, but often more cost effective than sourcing new water. As pressures on water systems grow, integrating reuse into core industrial operations is emerging as a critical strategy for both resilience and competitiveness.



Case story

Industrial water reuse at scale in German semiconductor production

Semikron Danfoss manufactures power electronic components for electric vehicles, renewable energy components, and other advanced applications. Like many semiconductor production sites, the facility relies on large volumes of ultrapure water for critical steps such as cleaning, sawing, and rinsing during production, all of which generate wastewater. To ensure efficient water usage, they have made water reuse a critical part of their resource strategy.

To reduce freshwater consumption and improve operational resilience, the site has implemented a multi-stream water reuse system that covers over 50% of its total water demand. Water from various process steps is collected and treated through filtration, ultrafiltration, and reverse osmosis, after which it follows a series of targeted reuse pathways depending on quality and purpose. Filtrate from sawing and grinding processes is reused as rinse or sawing water, and some is also used as process water. Discharge from rinse water recovery is reused in building systems, while the concentrate is used in the exhaust cleaning system. Additionally, concentrate from reverse osmosis is repurposed for toilet flushing and outdoor landscaping.

High-pressure pumps are deployed in the reverse osmosis process to help recover water for reuse or further purification into ultrapure water. In cases where water cannot be used directly, it is routed into the facility's ultrapure water production system, further maximizing the site's efficiency.

Semikron Danfoss' approach demonstrates that even highly demanding industrial environments can achieve substantial reductions in freshwater use without compromising performance. **In 2023 alone, over 120,000 cubic meters of reused water were supplied. This was equivalent to roughly 54% of total demand,** which has helped cut costs, reduce environmental impact, and build long-term water security.

Overcoming treatment and reuse barriers

Wastewater treatment plants are a critical element of reestablishing the water cycle by giving new life to "old" water. However, their high energy consumption means we must maximize efficiency wherever possible. It also means we must reuse as much as possible, particularly in industry.

1 High CAPEX and OPEX deter investment in advanced treatment technologies

Advanced treatment and reuse technologies, such as reverse osmosis, UV disinfection, membrane bioreactors, can deliver significant water and energy savings but their high upfront capital cost and energy demands limit uptake. **To solve this,** policymakers should incentivize industries to prioritize fit-for-purpose treatment — that is, cleaning wastewater only to the quality required for its next use. For example, water used for equipment cooling or surface rinsing can often be reused after minimal treatment, avoiding the high costs of bringing it to drinking water standards.

2 Regulatory and institutional uncertainty hinder adoption

In many countries, the lack of clear and consistent regulations, water quality standards, and permitting processes makes it difficult for industries and municipalities to confidently invest in water reuse systems. **To solve this,** technology providers must engage with policymakers to co-develop water reuse standards. Voluntary adoption of standards can build momentum and demonstrate feasibility — as seen with the uptake of ISO 46001 for water efficiency. In parallel, providing training and resources to regulators can help establish clearer and more supportive rules for water reuse.

3 Outdated wastewater systems limit technical viability

Industrial wastewater often contains substances that are hard or expensive to treat with standard technologies, which discourages reuse. **To solve this,** governments and industry should invest in research and innovation partnerships aimed at developing treatment solutions for challenging types of wastewater. For example, using modular or decentralized treatment systems can also make it easier and more affordable for smaller or harder-to-treat sites. Additionally, real-time monitoring helps track water quality as it enters the system, allowing treatment to be adjusted as needed — improving efficiency and reducing risks.

4 Wastewater treatment plants waste significant amounts of energy as heat

Wastewater is not just a waste product — it contains significant amounts of embedded energy, primarily in the form of heat. This heat is a clean and accessible resource, which today is simply being wasted. **To solve this,** existing technologies can be leveraged to capture this waste heat and repurpose it to meet heat demand elsewhere, such as through district heating networks, nearby industrial off-takers, or even for onsite space and water heating. This can help contribute to the energy neutrality of the sector.

Addressing efficiencies in the water-energy nexus involves action from all actors, from technology providers to decision makers, and requires bold policy action to turn ambition into reality.

Policy Recommendations

By 2030, global water demand will outpace supply by 40%,[138] while the water sector's energy use is set to more than double.[139] On top of this, in many countries more than 30% of treated water is not making it to the end user.[140] This is not just a climate risk — it's a competitiveness and security challenge. For policymakers to address the need to save more water, an integrated approach to the water-energy nexus is needed at all levels of government. Tackling the water-energy nexus means acting on four fronts: cutting waste, boosting efficiency, going digital, and making water count.

Minimize water loss

- Set up ambitious national targets on lowering water abstraction, leakage and consumption.
- Invest in proven technologies for leak detection, pressure management, and smart metering to reduce non-revenue water.
- Recognize that water loss is also energy and revenue loss — infrastructure upgrades should be guided by total cost of ownership, not just upfront price.

Embed energy efficiency in water policies

- Install data collection requirements and sharing platforms to show the real value of water.
- Require Minimum Performance Standards (MPS) for wastewater treatment plants, desalination facilities, and data centers.
- Consider integrating water efficiency into energy audits, taking into account local resource impacts.
- Set up guidelines and share best practices for industrial water reuse, and establish a national industrial water reuse target.

Incentivize digitalization

- Fund digital solutions which can relay real-time data on energy prices, distribution costs, and tariffs. Transparency in water prices and the correlation between price and wasted water and energy is critical for decision makers to take informed decisions to improve efficiency.
- Establish targets for data collection. The digital tools to increase the efficiency of water management exists, yet they are not widely adopted.

Make water count

- Encourage decentralized and flexible supply solutions to strengthen resilience against drought, climate shocks, and geopolitical risks.
- Support water reuse, fit-for-purpose treatment, and desalination with clear efficiency requirements.
- Match water quality to end use: high-purity water for drinking, lower-purity water for irrigation or cooling.

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Danfoss Impact is written to share our view on the potential of energy efficiency and electrification to transform our energy system. In the dialogue about the green transition, energy efficiency is often overlooked. One main reason for this is that experts and industrial leaders have inadequately explained its role in accelerating electrification to enable a future powered by renewables.

Drawing on evidence from credible sources, Danfoss Impact presents cases from a broad range of industries, highlighting solutions with great potential to save energy and reduce emissions in a cost-efficient and scalable manner. With this series, we also aim to demonstrate that the technologies we need for a rapid and sustainable green transition already exist today.

The greenest energy is the energy we don’t use.