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Unlocking the potential of wastewater

Using wastewater as a resource while protecting people and ecosystems

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UNLOCKING THE POTENTIAL OF WASTEWATER

Using wastewater as a resource while protecting people and ecosystems

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Executive summary

Treatment and management of wastewater are essential components of sustainable water resource management and play a key role in the success of the green transition. Wastewater should not be viewed as waste or a byproduct but as a resource.

Globally, an estimated 20 percent of all wastewater from households and industry is properly collected and treated. The United Nations' Sustainable Development Goal 6 aims to reduce the proportion of untreated wastewater entering water bodies by 50 percent by 2030. In Europe, 97 percent of generated wastewater is collected and receives treatment beyond the primary stage, yet only 69 percent undergo tertiary treatment. Denmark exemplifies a proactive approach to wastewater management, driven by environmental concerns that have spurred innovation.

The Danish water sector showcases a holistic approach to water management, setting a global example for optimising energy consumption and addressing emission challenges while maximising resource recovery. From phosphorus recovery to biogas production, Denmark demonstrates the potential of wastewater as a source of renewable energy and critical materials. A cornerstone in the Danish approach to wastewater is a high-quality treatment that surpasses regulatory requirements. The high level of cleaning is a result of both wastewater companies' ambitions to minimise the burden on the water environment, technical abilities and discharge fees.

Denmark's environmental journey stems from concern for its water resources and the environment in the 1980s when the aquatic environment showed significant signs of malady. This led to pioneering efforts in wastewater treatment to improve the aquatic environment. Over time, the efforts and innovations have reached new abilities and set new goals, such as the water sector's commitment to energy and climate neutrality by 2030. Through regulations, economic incentives and public-private partnerships, Denmark is well underway in achieving the goal of energy neutrality. The ambitious goal of climate neutrality is a challenge, in part due to the uncertainty of measurement and will likely not be met at the current trajectory. Although not realistically met by 2030, the goal continues to motivate actions and bring down emissions from the water sector.

The future of wastewater treatment lies in embracing innovation and investing in research and development. Continued collaboration between industry, government and research institutions will be essential to drive progress and ensure the water sector's contribution to a sustainable future. By transforming wastewater into a valuable resource, Denmark aimes to set an example for more sustainable water management practices, inspiring action and innovation worldwide.

FOREWORD

Wastewater treatment is of global importance

BY MAGNUS HEUNICKE, DENMARK'S MINISTER FOR ENVIRONMENT

Globally, it is important to act responsibly to protect people and the environment from intensive, untreated wastewater streams. We need efficient treatment of our wastewater to protect our health and natural environment. With the right technologies, wastewater can become a valuable resource, turning sludge from treated wastewater into energy and transferring heat from the treatment process to the district heating networks.

Severe environmental degradation of many inland and coastal waters around the world is the outcome of decades of uncontrolled discharge of wastewater. Globally, about 80 percent of wastewater is discharged untreated to the surrounding environment, which has major consequences for human health, biodiversity and the environment.

Denmark realised the severe effects of a growing population and a blooming industry at a very early stage. Today, as a result of progressive efforts, more than 95 percent of all wastewater is treated.

In Denmark, wastewater is considered a valuable resource.

The Danish water sector has a goal of becoming energy and climate neutral by 2030 - and perhaps even net producers of energy. That is an ambitious goal which requires cooperation between Danish authorities, water utilities, companies and organisations if we are to create more innovative solutions, adding value for both water consumers and the society as a whole.

Today, wastewater is a resource for reuse, extraction of nutrients, energy production and soil improvement. And this is an example of how Denmark contributes to finding solutions to some of the world's major water and climate challenges, in accordance with a number of the United Nations' Sustainable Development Goals.

If properly treated, wastewater may for example be reused as technical water in some industries, as irrigation water for crops and for recreational purposes. The number of available solutions is plenty but to harvest the full potential of investments in wastewater treatment, it is crucial to look ahead and think long-term. Wastewater should no longer be thought of as a problem but as a resource. We must make the most of the water we have, including wastewater.

This white paper features a series of best practice examples of wastewater treatment – both centralised and decentralised. Although many of these solutions have been created within a Danish context, they are scalable and applicable for a global audience.

Magnus Heunicke
Denmark's Minister for Environment

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CHAPTER 1

The ripple effect of legislation

Denmark's environmental journey began decades ago, driven by the need to protect the aquatic environment and limited water resources. Today, the Danish water sector applies innovative wastewater treatment, aiming for energy and climate neutrality by 2030. Public-private partnerships and EU alignment underscore its commitment to sustainability, setting a global example for transformative solutions in water management.

Geographically, Denmark is challenged by the lack of major water bodies to discharge pollutants from the cities. Consequently, environmental concerns have been a priority for many years, leading to strict regulations implemented since the 1980s. Danish standards for discharging into sensitive waters were further tightened in the 1990s. Much of Denmark's environmental legislation has been adopted nearly in its entirety by the European Union.

Regulation as a driver for development

Today, more than 95 percent of all wastewater in Denmark is subject to tertiary treatment. Denmark was one of the pioneers in taking significant steps to reduce the negative effects of urban wastewater discharge on aquatic ecosystems. Instead of merely diverting pollution away from cities, innovative technologies treat urban sewage water to high standards that limit the negative and pollutive consequences on the surrounding environment. This has improved the quality of life in and around Danish cities both for humans and nature, and increased the appeal of the surrounding areas.

Public-private goal setting

In 2019, the Danish government enacted legally binding targets that oblige Denmark to achieve a 70 percent reduction compared to 1990 levels in its greenhouse gas emissions by 2030. To meet this goal, 14 public-private Climate Partnerships were established to bring together ideas and uncover barriers to the green transition. The partnership on water and waste set a goal of becoming energy and climate neutral by 2030. In partnership with the government, the private sector set forth five suggestions for the water sector, proving it to be an ambitious sector:

1. Reduction of direct greenhouse gas emissions in the wastewater sector
2. Increased energy efficiency in the water and wastewater sector
3. Avoidance of rainwater and unauthorised water in the wastewater system
4. Increased energy production via biogas and heat pumps
5. Export efficient water technology to achieve global impact

Efforts and innovations in energy-efficient measures have significantly advanced the Danish water sector, bringing it closer to achieving energy neutrality. Additionally, the sector is committed to operational climate neutrality and will, in the coming years, develop methods to measure this progress to capture the extent of its achievements.

The 2023 revision of the EU's Urban Wastewater Treatment Directive will further accelerate the need for transformative solutions. The revision focuses on improved treatment of wastewater, increased reuse of wastewater, better monitoring, energy neutrality and the polluter pays principle for cosmetics and pharmaceutical industries.

CHAPTER 2

The structure of the Danish wastewater sector

The economic structure of the Danish water sector incentivises Danish wastewater treatment plants to clean wastewater far better than the requirements set by the authorities. Discharge fees combined with technical abilities and the wastewater companies' ambitions to minimise the burden on the water environment result in a generally high level of treatment.

As the only country in the world, Denmark's water supply is 100 percent groundwater based. Relying on a groundwater model places high responsibility and requirements on effluent water and, therefore, on the Danish wastewater treatment plants and how wastewater is treated and cleaned.

In 2022, 95.7 percent of all wastewater in Denmark was subject to full biological treatment. 600-800 million cubic meters of wastewater runs through Denmark's more than 700 wastewater plants annually, where approximately 90 percent of nitrogen and phosphorus is removed before the water is led out into nature. Wastewater treatment is the cost-heavy part of the water cycle in Denmark, where the cost is reflected in the price of water.

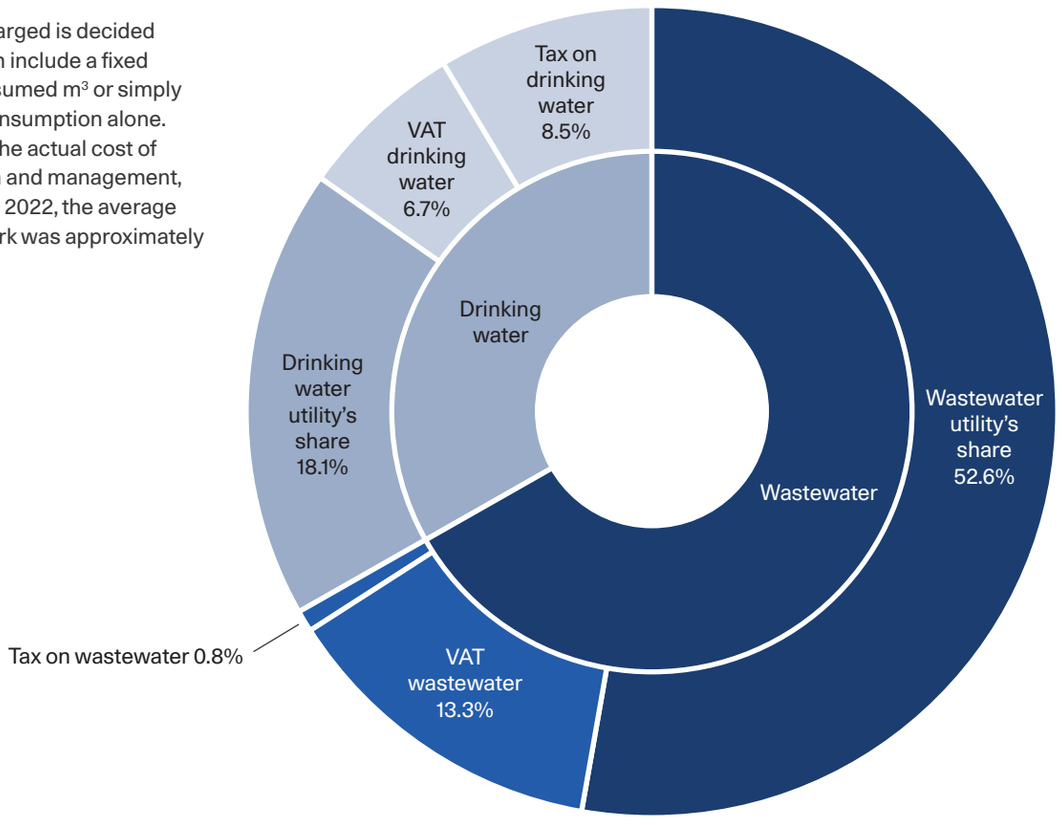
Polluter pays principle
Water and wastewater services are in many countries considered public goods paid by government funds. However, in Denmark and other EU member states, the 'polluter pays principle' is applied to both domestic and industrial users. This requires that the costs of wastewater collection and treatment are funded through water tariffs.

To complement the existing regulatory framework, a discharge tax has been implemented that places the burden on the polluter – in this case, the wastewater treatment facility. This means that the polluter must pay a tax for every kilogram of discharge for the three main parameters: organic matter (BOD), phosphorus and nitrogen. The result has been a very innovative and progressive optimisation strategy for the water sector in Denmark, which now can be expected to be pushed even further by the private sector with the revised EU Urban Wastewater Treatment Directive.

Cost-efficient treatment through centralisation
Centralising wastewater treatment has proven to be a cost-efficient approach in many regions, increasing the efficiency and surplus of heat and energy production. In Denmark, 50 percent of all wastewater is treated at just 31 centralised plants.

Danish water prices

The price of water charged is decided by each utility and can include a fixed fee + charge per consumed m^3 or simply a charge based on consumption alone. The price will reflect the actual cost of production, operation and management, a full cost recovery. In 2022, the average water price in Denmark was approximately EUR 10 per m^3.



These facilities enable significant reductions in operational costs, particularly through decreased labour, maintenance and expenses, and improved energy efficiency.

In densely populated areas, larger centralised treatment plants are optimal, supporting the demand for energy self-sufficiency and resource recovery. Conversely, rural areas benefit from decentralised, low-technology solutions. However, rapid urban growth and water scarcity are prompting innovative solutions, such as compact treatment units and membrane technologies, which are becoming competitive for smaller communities.

Denmark's experience highlights the advantages of centralisation, including advanced treatment opportunities like energy-efficient processes and phosphorus recovery. These sophisticated technologies are feasible and cost-effective only at larger plants, underscoring the economic benefits of a centralised approach to wastewater treatment.

Download the latest report here: www.danva.dk/waterinfigures

CHAPTER 3

Wastewater as a source of energy

Great examples of energy optimisation have been set by the Danish water industry and at the same time emission challenges have been duly addressed. Sustainability is key for the future of Danish water businesses.

The wastewater sector in Denmark is at the forefront of development in relation to both energy conservation and emissions reduction. Several leading utilities in Denmark have proved that energy neutrality is an achievable goal, meeting the challenges with aggressive energy reduction and conservation programs, and maximising energy production in the form of biogas production.

Driving economic and environmental gains in water treatment

Denmark's commitment to the aquatic environment and sustainability is embodied in its national goal to achieve energy neutrality and strive towards climate neutrality by 2030. To meet the 2030 objectives, wastewater treatment plants across Denmark have conducted comprehensive energy assessments to identify and implement the most effective energy-saving measures. These initiatives include the deployment of advanced online monitoring and energy management systems. Such improvements can lead to significant reductions in energy consumption. This strategic approach not only supports Denmark's environmental goals, but also offers substantial economic benefits by lowering operational costs and enhancing the sustainability of water treatment operations.

From wastewater to watts

A progressive implementation of energy-efficient equipment as well as process optimisation has put wastewater treatment plants in the position of being net producers of energy. They boast an impressive net self-sufficiency rate of 77 percent, achieved through the innovative use of anaerobic sludge digestion leading to the production of valuable biogas used for the production of electricity or in some cases injected into local or national gas grids.

Excess heat produced in the process is cleverly integrated into the district heating networks, exemplifying a successful circular economy approach and adding to the neutrality agenda. Even heat pump technology is in some cases implemented using the temperature in the effluent steam as a heat source for the district heating system, setting a benchmark for future initiatives.

Green transition through wastewater innovation

Denmark has adopted ambitious goals for emission reduction. For the wastewater sector, this means that process emissions in the form of nitrous oxide (N_2O) and methane (CH_4) are closely followed and measured, and control and abatement initiatives have been initiated.

Danish utilities have both measured and tested control strategies for reduction of the N_2O-emissions from the biological conversion of ammonia to free nitrogen. This work has been supported by Danish inventions in the sensor industry and is supported by the Danish Environmental Protection Agency. Despite many initiatives, there is still some way to go before full control and minimisation will be achieved.

With the increased utilisation of biogas production, more attention has been given to the adverse effect of leaking of CH_4 from the systems. Numerous initiatives aiming at ensuring optimal utilisation and minimising emission have been implemented, even regular audits are mandatory to ensure that leaks are not leading to emissions.

Increasing efficiency and quality in municipal wastewater recycling

Reducing the energy consumption of a reverse osmosis operation while maintaining the permeate quality is a delicate balancing act. Municipal wastewater treatment plants often use conventional anti-fouling brackish water membranes to improve operational stability, however, these membranes have high rejection rates and are not energy efficient. Aquaporin and PUB, Singapore's national water agency, have partnered to develop the world's first biomimetic low-energy Aquaporin membrane demonstration for NEWater. NEWater is a state-wide project where used water, including wastewater, is treated to ultra-clean, high-grade reclaimed water for consumption.

Aquaporin's solution is the Aquaporin Inside® CLEAR series. Utilising biomimicry, advanced membrane chemistry and smart element design, the membranes require less feed pressure while at the same time bringing stable operation and high permeate quality to municipal reverse osmosis wastewater recycling.

Lower feed pressure reduces energy use by up to 30 percent. A 30 percent reduction in energy consumption results in important potential benefits for companies and local authorities, such as reduced operating costs and lower carbon footprint, while also helping municipalities increase resilience to energy shortages and price fluctuations.

CONTRIBUTORS

Aquaporin

LOCATION

Singapore

From eight to one innovative, centralised wastewater treatment plant

The existing eight wastewater treatment plants in Assens were unable to keep pace with the municipality's growth and fell short of economic and environmental standards. To address these challenges, a new, centralised wastewater treatment plant was established in a new utility park. The new facility offers increased capacity and flexibility for future urban development, as it is designed for 100,000 person equivalents (PE), with the capacity to accommodate an additional 50,000 PE.

An innovative aspect of the new plant is its ability to generate energy. This is made possible by integrating a biogas plant, which converts industrial wastewater and sludge into energy, thereby promoting sustainability and aiming for a CO_2-neutral operation by 2029. This aligns with broader environmental goals and reduces waste significantly.

The benefits of the new treatment plant include enhanced operational efficiency, reduced costs and improved reliability in wastewater treatment. By decommissioning outdated facilities and ceasing discharges into sensitive areas, the project aims to greatly improve the aquatic environment. It also prepares for future regulatory and technological advancements.

Assens Utility was the employer for the project and COWI A/S served as the employer's adviser.

CONTRIBUTORS

COWI A/S, Assens Utility, Envidan A/S, NCC A/S - Jacobsen & Bindkilde A/S and Cubo A/S

LOCATION

Assens, Denmark

Going beyond energy efficiency

The Kishwaukee Water Reclamation District (KWRD), serving DeKalb and Northern Illinois University, aims to be energy neutral by 2025, aligning with its mission to protect public health and the environment through efficient wastewater services.

To achieve this, KWRD installed two combined heat and power (CHP) generators from NISSEN energy as part of a comprehensive net-zero energy plan. These NPM 375 generators convert biogas from sewage into electricity, each supplying 375 kW of electricity and 462 kW of heating.

The first generator, installed in 2020, reduced power consumption by 60 percent but could not meet all energy needs. To generate sufficient biogas for a second generator, the facility began processing food waste and restaurant grease. Initially planned for 2025, the second generator's installation was expedited thanks to a donation from Facebook (now Meta) and a grant from the Illinois Clean Energy Community Foundation. The second CHP generator is now operational, joining the first one. Together, they supply 125 percent of the facility's electrical energy needs, moving KWRD closer to its energy neutrality goal.

CONTRIBUTORS

NISSEN energy

LOCATION

Kishwaukee, Illinois, USA

Joint Danish effort to meet local challenges

The Changqing district, located in the city of Jinan in Shandong, China, was challenged by lacking sewage capabilities. In a project to solve the local issues, the Jinan Economic Development Zone sought advanced technologies to address the challenges. At the same time, the solutions had to contribute to China's 'dual carbon' policy where reduction in CO_2 and energy efficiency are in focus.

In a joint effort, Danish water companies, including AVK, Danfoss and Landia, demonstrated how Danish water technologies in unison could help the city of Jinan reach their goals. This involved gates and valves from AVK, frequency converters and soft starters from Danfoss, and sewage pumps from Landia.

With the implementation of the new technologies, a 10 to 15 percent reduction in energy consumption was made possible. Moreover, the solutions would secure a decrease in the error rate, increased process efficiency, improved sewage treatment capacity in the Changqing district and, overall, contribute to the green, economic development in the city of Jinan.

CONTRIBUTORS

AVK, Danfoss and Landia

LOCATION

Shandong Province, China


Photo credit: Andreas Große

Identifying N_2O in Flensburg's wastewater treatment

In 2022, the TBZ Flensburg wastewater treatment plant conducted measurement campaigns to identify key sources of N_2O. The plant's unique setup led the engineers to select seven measurement points across nitrogen degradation sections to accurately identify N_2O sources and pathways for better mitigation strategies.

The measurement campaigns, each lasting one to two weeks per location, were conducted from October 2022 to February 2023. The flexibility of using the Unisense Environment N_2O Wastewater System at various measuring points was a significant advantage, as stored data could be transferred onto an USB for viewing and evaluation. The campaigns showed low N_2O formation in the main stream and typical levels in the side stream treatment, with two specific sources identified. Due to seasonal variations in N_2O production, year-round monitoring is essential for accurate data. Future measurements will contribute to the Flensburg plant's CO_2 equivalent accounting and climate neutrality efforts.

The next steps include integrating N_2O monitoring in the process control system and using it for carbon source dosing control. Long-term monitoring will identify fluctuations and help implement measures to improve plant performance.

CONTRIBUTORS

Unisense Environment

LOCATION

Flensburg, Germany

CHAPTER 4

Resource recovery from wastewater

Today, the wastewater sector is facing a paradigm shift, moving away from pollution abatement to extract value from wastewater. Consequently, wastewater treatment plants are being redesigned from treatment facilities using energy and chemicals, towards resource recovery facilities delivering different valuables.

Wastewater is a valuable and sustainable source of water with organic materials, metals and nutrients from which other high value products as energy, fertilisers or bioplastics can be obtained.

Direct use of urban sewage sludge in agricultural land is a common practice for nutrient recovery. In 2021, around 76 percent of the produced urban sewage sludge in Denmark was directly applied to farmland. However, using sewage sludge for agricultural purposes is typically costly for a wastewater treatment plant. The potential risk of contaminant content, such as heavy metals, micropollutants and pathogenic organisms, as well as a relatively small nutrient and organic matter proportionate to the total waste mass, increase costs. Consequently, new sludge valorisation technologies are being developed and applied.

Sludge valorisation as biochar

Biochar produced by pyrolysis of sewage sludge is a method of eliminating micropollutants. Pyrolysis is a thermal decomposition process that occurs in the absence of oxygen when organic matter is heated to more than 300°C. Today, two full-scale pyrolysis plants are in operation in Denmark at Fårevejle wastewater treatment plant and at Søndersø wastewater treatment plant with two more projects being underway.

The solution consists of a combined steam dryer and a pyrolysis oven, where sewage sludge is pyrolysed at 500-800°C resulting in a biochar rich in nutrients and a volatile pyrolysis gas. Approximately 28-50 percent of the sludge's carbon can be found in biochar, while the rest is used for energy when burning the pyrolysis gas. Both digested and undigested sludge with varying levels of dry matter can be treated. Since biochar consists of around 28-50 percent carbon, it can be used as a soil amendment. Most of the carbon remains in the soil for hundreds or thousands of years. In this way, turning sludge into biochar can effectively reduce CO_2-emissions.

Another advantage of using pyrolysis is that the amount of sludge is significantly reduced to 1/10 in volume when it comes out as biochar. The biochar is stable, free of pathogenic bacteria, odourless and rich in phosphorus, carbon and other minerals. Moreover, it can be used as a soil improvement. While pyrolysis has a high maturity level, it is a relatively new technology, especially with sewage sludge as input. Danish wastewater utilities are testing and helping to improve the process which is a promising alternative for sludge valorisation.

Pyrolysis revolution: transforming waste into valuable resources

Traditional sludge spreading is harmful due to microplastics, pharmaceuticals, heavy metals and PFAS, posing health and environmental risks. Tightening regulations and rising costs have further strained budgets at the Fårevejle treatment plant, which is part of Odsherred Utility. As a solution, Odsherred Utility has adopted AquaGreen's advanced pyrolysis technology to transform sewage sludge into nutrient-rich biochar, eliminating harmful practices of spreading sludge on farmland. This innovative system converts sludge into biochar, thereby removing PFAS, capturing CO_2 and recovering valuable resources like phosphorus and potassium.

AquaGreen's system, using steam-drying and pyrolysis, operates cost-effectively and generates revenue through biochar sales, carbon removal credits and excess heat. The HECLA® Setores 1.000 plant reduces greenhouse gases by 1,800 tonnes of CO_2 equivalent, produces 2,000 MWh of energy and stores 500 tonnes of carbon in biochar anually.

This method offers a sustainable alternative to sludge disposal, combats climate change, prevents groundwater pollution and reduces transportation needs by 90 percent, and ultimately cuts handling costs by up to 90 percent while generating new revenue streams.

CONTRIBUTORS

AquaGreen and Odsherred Utility

LOCATION

Fårevejle, Denmark

CHAPTER 5

The digital transformation of the wastewater sector

The water sector is facing a growing number of challenges affecting all aspects of operations. Taking a data-driven approach to running a wastewater treatment plant opens new opportunities for optimisation. The Danish water sector has already proven that digitalisation holds the key to radical transformation.

Denmark is one of the most digitalised countries in the world. As the surrounding society has become increasingly digital, so has the water sector. Today, most wastewater facilities see digitalisation as necessary for overcoming the current and future challenges facing them. However, while the steps involved in a wastewater treatment plant's digitalisation journey are the same, their starting points, individual needs and ambitions may not be.

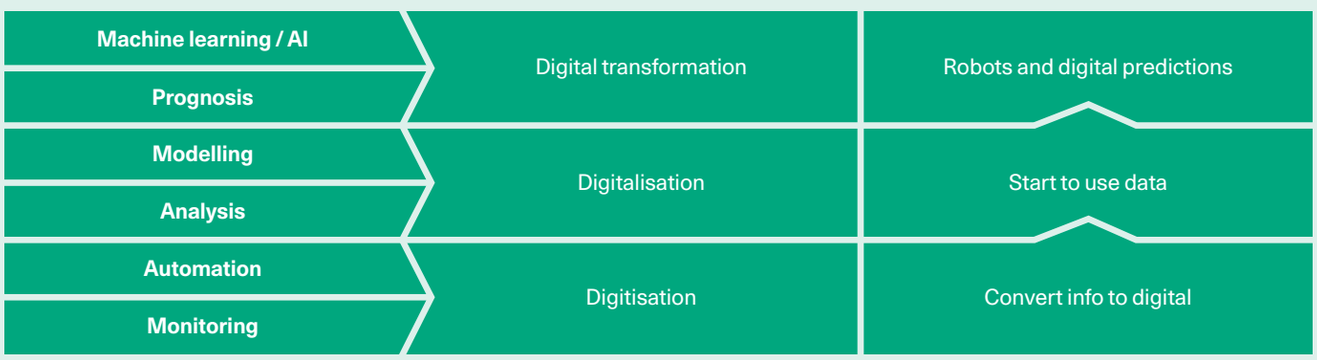
Optimisation through digitalisation

Regardless of the starting point, a digital transformation affects the entire facility and is a means for improving operations and investments, attracting and maintaining the workforce, and monitoring and documenting performance towards stakeholders, such as authorities.

Automated management systems are widely implemented across wastewater treatment plants in Denmark. By digitally monitoring water pressure, temperature, microbial levels and other key indicators, these systems enable utilities to prioritise their daily efforts effectively. This approach not only saves time in locating leaks and addressing issues that require onsite attention, but also facilitates nearly unmanned operation of the treatment plants. For instance, alarm systems can digitally monitor nighttime flow data, ensuring efficient and continuous oversight without the need for constant human presence.

Furthermore, ongoing asset monitoring can alert the utility company of actions needed before malfunctions occur in the systems or service connections. This saves time and cost-consuming shutdowns of the treatment plants. Asset management systems can also be used for predicting cloudbursts, assessing the capacity of and controlling water flow pressure on the sewers.

The figure below is a good and comprehensible way of framing the three concepts and their distinctions:



This model shows a development from digitisation to digitalisation followed by digital transformation.

- Digitisation refers to the process of converting information into a digital (i.e. computer-readable) format.
- Digitalisation is the process in which aspects of social and work life are restructured around digital communication.
- Digital transformation is the adoption of digital technology by a water company or utility. Common goals for its implementation are to improve efficiency, value or innovation.

Are we there yet?
Digitalisation is not a one-step transformation. The digital journey in Denmark has been underway for the past 20 years. A gradual digital transformation enhances performance opportunities by progressing through three stages: digitisation, digitalisation and digital transformation.

Digitisation is the first step, involving the conversion of analogue information into digital form, such as scanning documents. This improves performance by making data more accessible and easier to manage. The second step, digitalisation, uses digital technologies to change and improve business processes, such as automating tasks and integrating systems, leading to increased efficiency and reduced costs. Finally, digital transformation represents a comprehensive shift in how an organisation operates, incorporating digital technologies into all areas of the business.

This step drives innovation, improves customer experiences and opens new business opportunities. Each step builds upon the previous one, collectively enhancing the organisation's overall performance potential.

However, experience has shown that digital transformation is like aiming at a moving target as new regulations, expectations, threats and technological advancements constantly bring new solutions to the market. Fortunately, the foundation has been laid for Danish wastewater plants in close collaboration with technology providers to ensure that new challenges and opportunities are continuously addressed and incorporated.

Improving wastewater treatment through digitalisation

BIOFOS Utility, treating wastewater in the Greater Copenhagen area, has enhanced the operation of its three large treatment plants through a commitment to sustainability and innovation. The goal has been to maximise the utilisation of existing facilities, minimise environmental impact and ensure optimal and compliant operation under diverse conditions, including varying weather patterns.

The primary challenge has been to improve operational efficiency, particularly in response to the growing population in the catchment area. To meet these challenges, BIOFOS initiated a collaboration with Krüger A/S 20 years ago to develop and implement data-driven technology, today known as Hubgrade. Over the years, numerous projects have been undertaken, ranging from enhancing process understanding to developing new software. This approach has revolutionised plant operations, leveraging specific process data and external inputs such as rainfall, electricity prices and effluent regulations.

Operators now possess the tools and knowledge to manage the complexities of treatment effectively, setting targets in real-time that balance priorities such as cost efficiency, capacity utilisation, compliance and climate impact.

CONTRIBUTORS

Krüger A/S and BIOFOS

LOCATION

Greater Copenhagen, Denmark

A digital twin to support wastewater treatment operations

Gruppo CAP has implemented DHI's TwinPlant at the Bresso-Niguarda wastewater treatment plant located near Milano, Italy. This is part of a digitalisation plan aimed at optimising operations through real-time data and advanced process modelling. TwinPlant integrates online sensors and process models, allowing continuous evaluation of performance and identification of strategies to improve efficiency, energy use and resource recovery.

DHI's MIKE OPERATIONS platform collects, stores and validates sensor data, while a plant-wide WEST model describes treatment processes and estimates energy balance. The graphical dashboard offers access to measurements, simulation results and comparisons of operational strategies using customised KPIs. TwinPlant predicts plant performance in real-time, enabling operators to test and evaluate conditions and strategies in a virtual environment.

Results have included fast integration of online data and process models, identification of optimal operational strategies through scenario analysis and a user-friendly dashboard that supports scenario execution and displays KPIs. This helps operators visualise operations against model predictions, implement strategies through SCADA and verify system performance, enhancing overall performance.

CONTRIBUTORS

DHI and Grupo CAP

LOCATION

Milano, Italy

CHAPTER 6

Treating and recirculating industrial wastewater

Both industries and public utilities are increasing their focus on improving discharge water quality, removing harmful substances and recirculating treated wastewater. The threat of toxic substances and the revised EU directive on urban wastewater are key factors driving innovation.

Water recycling is becoming more relevant with the growing scarcity of water resources combined with increasing demand for water. Industry water consumption accounts for more than 50 percent of the EU's total annual abstraction and industrial wastewater presents a mounting challenge to municipal treatment facilities due to its diverse range of toxins, temperature fluctuations, pH imbalances and the sheer volume and variety of hazardous substances it contains.

Wastewater from food and beverage industries is generally well suited for centralised treatment since it is often rich in easily degradable organic compounds, which provide nutrients for the growth of microorganisms and thereby enhance the biological processes. On the other hand, wastewater from various manufacturing processes, like pharmaceutical, electroplating, petrochemical and textile production, has a much more complex composition and often includes substances that do not respond to biological treatment.

Potential for savings and innovation
A recent study showcases the enormous potential of reducing, reusing and reclaiming industrial water in the production of food and beverages, pharmaceuticals and other light industries. The water saving potential of circularity is estimated to be 50-70 percent of the industry's current water consumption, proving both an economic and ecologic benefit. Additionally, industries are under pressure to develop innovative solutions to use technical water, that is, water unfit for human consumption. This technical water, sourced from alternative sources such as treated municipal wastewater, can be used in applications where drinking water quality is not imperative.

Utilities investing
Many utilities are looking into investing in a fourth treatment step to remove cosmetic and medicinal residues. As briefly mentioned in chapter 1, this development is driven by the revised EU directive on urban wastewater treatment, which, amongst others, imposes the fourth step to all wastewater treatment plants above 150,000 PE and wastewater treatment plants above 10,000 PE discharging to sensitive areas by 2045. For industrial wastewater stemming from the cosmetics and pharmaceutical companies, a minimum of 80 percent of the costs for this fourth step must be covered by the companies themselves. In the new EU directive proposal, extended producer responsibility is put on these industries giving them clear incentives to develop more degradable products and invest in the optimisation of their own wastewater treatment, which some Danish corporations have already initiated.

Proposed ban on PFAS
PFAS has also become a growing headache driving innovation. To prevent future pollution, an EU ban on 10,000 different PFAS substances, the so-called 'forever chemicals', seems to be on its way. This ban has been proposed by Denmark alongside Germany, the Netherlands, Norway and Sweden.

ReUse: recycling of resources from industrial wastewater streams

Today, many companies pay wastewater treatment plants to get rid of their industrial wastewater, but often the water contains resources that could be used by the company itself or others. Examples of wasted resources can be hot process water, cooling water, residues, soap and other cleaning chemicals. It is important to capture the resources before being mixed with other products which complicates the resource extraction.

Addressing this issue, a large consortium along with the Danish Environmental Protection Agency is investing approximately EUR 12 million to show how resources in industrial wastewater can be mapped, valued and utilised for the benefit of Danish companies' business and the circular economy. The aim of the initiative is to extract at least half of a resource currently discharged from three selected companies and involves mapping the production processes in the companies to clarify resource flows and thereby identify the hidden resources. Moreover, resources are prioritised based on technical feasibility and economic potential, and the most cost-effective solutions for the specific company are tested and verified.

Nopa Nordic has already identified several opportunities for recycling both water and resources, and the next step is to evaluate the technologies followed by full-scale implementation.

CONTRIBUTORS

DTI - Danish Technological Institute, Aquarden, CP Kelco, Hartmann A/S, Nopa Nordic, Tetra Pak Filtration, Silhorko-Eurowater, Viegand Maagøe and Q-Interline

LOCATION

Aarhus, Denmark

Water and resource recovery in the pharmaceutical industry

The pharmaceutical industry has traditionally prioritised speed-to-market over environmental sustainability. However, integrating green solutions early in the production development phase is crucial.

A significant environmental challenge is the extensive use of non-recycled water and organic solvents. By incorporating recycling solutions from the design phase, organic solvents and water can be regenerated to meet regulatory standards, significantly reducing overall usage.

In Phelimin polymer production, substantial water, ethanol and other materials are consumed. To address this, several solutions have been implemented. A direct filtration unit with PVDF membranes separates the polymer product and recovers synthesis oil, reducing resource consumption. A water treatment system produces and reuses purified water, with Ultraaqua's Vacuum-UV-based advanced oxidation process reducing microorganisms and organic matter. This system also prepares used purified water for reuse in the ultrapure water plant. Additionally, horizontal distillation technology recycles ethanol, and a reverse osmosis unit recovers template molecules and phosphate buffer.

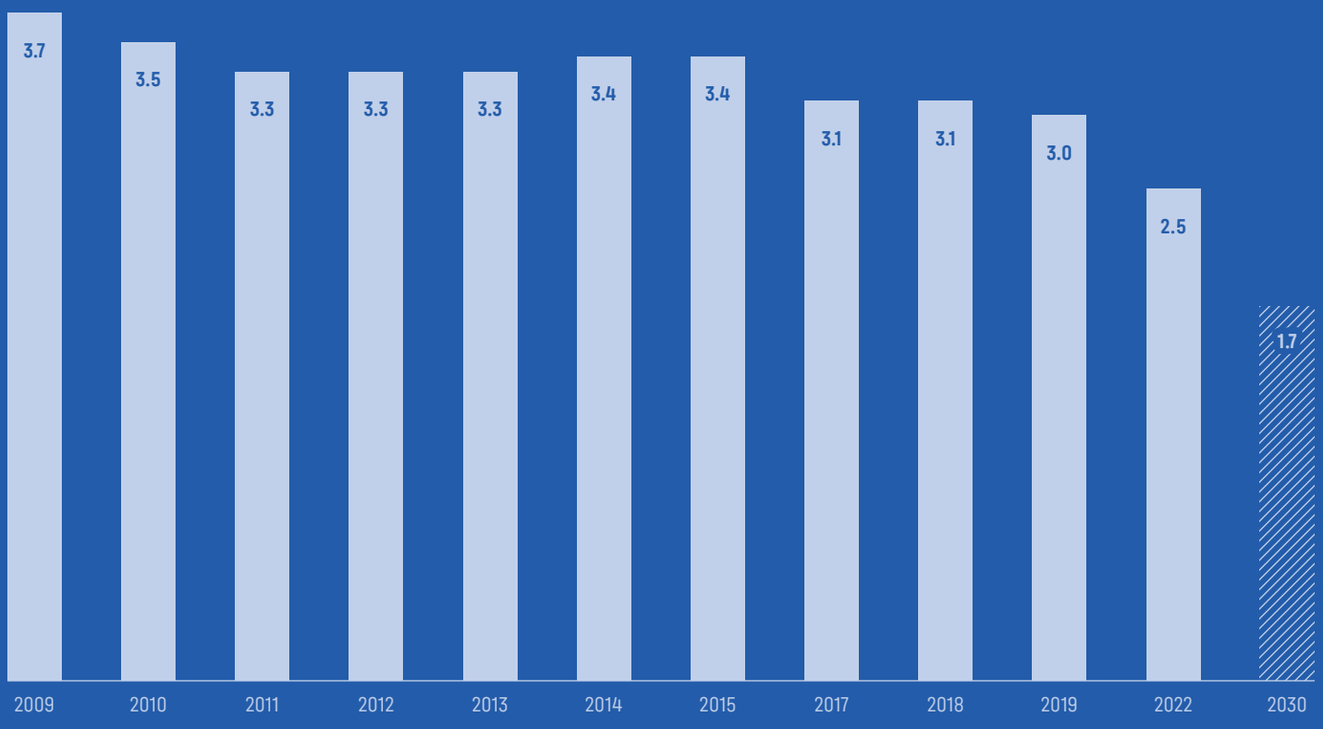
CONTRIBUTORS

ULTRAAQUA, MipSalus and Process Design A/S

LOCATION

Hørsholm, Denmark

Relative Water Consumption (hl/hl) Carlsberg



* The data is a reflection on the average performance of the sites Carlsberg had in the reporting year.

Halving water usage at Carlsberg's largest brewery in Denmark

A new industrial water recycling plant will turn Carlsberg's largest brewery in Denmark into the most water efficient brewery in the entire Carlsberg Group, and probably also the world. Carlsberg's Fredericia brewery has consistently focused on resource management and water reduction, but even more advanced water recycling technologies were required to reach the ambitious targets set in Carlsberg's 'Together Towards ZERO' programme. Carlsberg decided to construct a new Total Water Management plant in close cooperation with the consultancy company NIRAS.

The ambition was to recycle 90 percent of all process water in the facility and halve the overall water usage from 2.9 to 1.4 hectoliters of water per hectoliter of produced beer, making it Carlsberg's first brewery to virtually eliminate water waste. The project uses advanced water treatment technologies such as high efficient reverse osmosis and advanced oxidation processes in order to deliver water of drinking water quality. Grundfos has identified the most optimal pumps and dosing systems for the entire treatment and purification process, and Grundfos pumps help along every step of the process covering 95 percent of all pumps on site. Due to the production of biogas in the pre-treatment step, the plant produces approximately four times the energy used for the processes.

Together with NIRAS and with the implementation of efficient technologies, Carlsberg has achieved a significant reduction in water use at the Fredericia brewery, demonstrating how collaboration and innovative solutions can lead to more efficient water usage. The project will serve as a learning platform for all Carlsberg breweries worldwide.

CONTRIBUTORS

NIRAS, Grundfos and Carlsberg

LOCATION

Fredericia, Denmark

CHAPTER 7

Tackling today's challenges with the innovations of tomorrow

Current and future challenges in wastewater treatment include the handling of xenobiotics such as PFAS, pharmaceutical substances, microplastics, as well as reducing emissions of greenhouse gases such as methane and nitrous oxide. At the same time, there is a growing interest in recycling wastewater as a water resource for Power-to-X plants that requires ultrapure water.

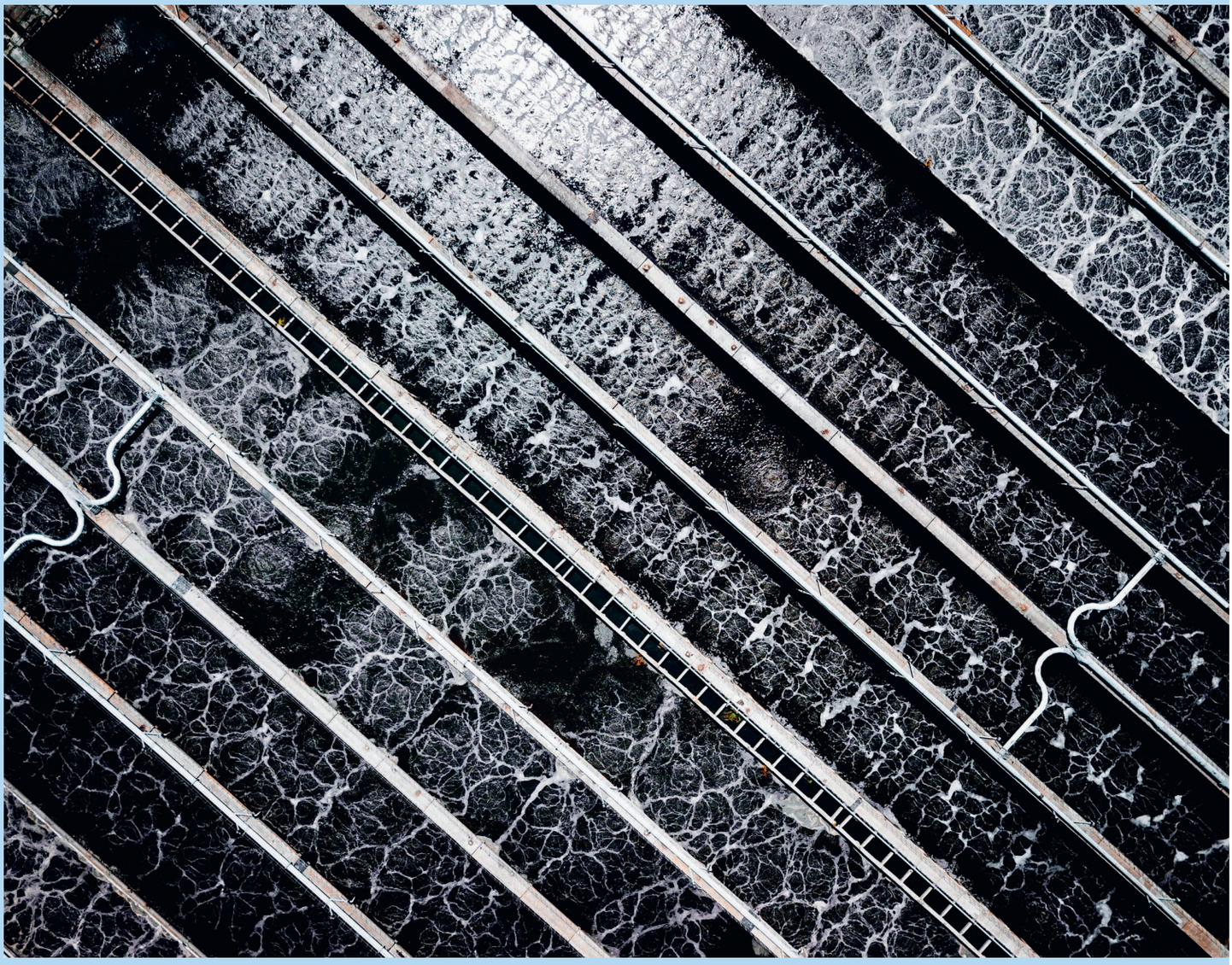
Innovative solutions for handling contaminants include advanced technologies such as ozonation, activated carbon filtration, membrane filtration and the like, all of which are able to remove micropollutants from wastewater. In addition, there is research into the development of sorbents and advanced oxidation techniques for the removal of PFAS and medicinal residues.

To mitigate greenhouse gas emissions from wastewater, the capture and utilisation of methane (CH_4) as an energy source in biogas facilities is already underway, particularly in larger Danish treatment facilities. Efforts are intensifying to optimise this process and prevent CH_4 leakage into the atmosphere. In addition, there are increased efforts to implement processes that can minimise nitrous oxide (N_2O) emissions by optimising purification processes and possibly finding economically profitable methods for decomposition of the N_2O that will still be produced.

To achieve climate neutrality in future wastewater treatment plants, despite increasing demands for enhanced treatment — which usually requires more energy and chemicals such as activated carbon — introducing carbon capture technology may be essential. Therefore, carbon capture systems need to be developed for efficient operation on a relatively small scale, suitable for implementation at wastewater treatment facilities. A point of awareness is that CCUS generates wastewater which needs to be treated locally or externally before discharge into a receiving water body. This requires further innovation and investment.

Powering the future with ultrapure wastewater

In Denmark, Power-to-X (PtX), which is the conversion of renewable electricity into a variety of end products (X) via electrolysis, will represent a new large-scale energy source. However, the electrolysis process in PtX production requires substantial amounts of extremely pure water.



Experts across industries are currently investigating different water sources, such as contaminated groundwater, surface water, seawater and wastewater, to examine which have the potential to be treated to an ultra-pure level and utilised for electrolysis.

Using seawater poses a challenge due to the desalination process, which produces brine, also known as reject water, and necessitates effective management. Proper reject water treatment is crucial, as even a slight increase in water salinity can negatively impact marine ecosystems. Sustainable solutions for handling reject water from PtX production have yet to be developed. Moreover, attention should also be given to the environmental impact of reject water from PtX, which remains unknown and could pose a significant challenge.

Treated wastewater is another potential water source for PtX production in Denmark. Advanced treatment processes, such as advanced oxidation, membrane filtration and biological treatment, are required to remove contaminants like organic compounds and nutrients producing high-quality water suitable for electrolysis. Although the optimal water source or combination for PtX production remains undetermined, it is clear that the water sector will play a crucial role in developing Denmark's PtX infrastructure.

Investing in our future

Fostering innovative solutions is necessary to solve the present and future challenges facing our society. Optimising and improving wastewater treatment technologies and processes depend on investments in research and development, and collaboration across the water sector. Investments are already being made, but emphasis should be on securing a continuous evolvement as these investments are key to securing the water sector's contribution to a more sustainable future.

Leachate PFAS-removal technologies from landfills in Odense

In Denmark, landfill leachate treated at municipal wastewater treatment plants is a major PFAS source, however, the municipal treatment plants are not designed to remove PFAS effectively, leading to contamination of the aquatic environment. This is also the case for VCS Denmark that receives leachate from Odense North Environmental Center (ONEC) at Odense North West (ONW) wastewater treatment plant.

In 2022, Odense Renovation commissioned Ramboll to conduct a PFAS-mapping at ONEC. This study included analyses of individual landfill cells and the overall leachate flow over an extended period. The mapping revealed high concentration variations across landfill cells. The leachate transported to ONW treatment plant had PFAS22 concentrations ranging from 2,400-8,000 ng/l, dominated by short-chained PFBS.

A year later, a new project to evaluate removal technologies, such as foam fractionation, flocculation with FluorFloc and ion exchange resin, was initiated. So far, the project has shown that using foam fractionation and targeted flocculation have varied efficiencies. Foam fractionation or flocculation alone is insufficient to meet aquatic environment limits, prompting experiments with ion exchange resin columns, which can achieve very low PFAS levels but are costly due to rapid saturation.

The project will continue until late summer 2024.

CONTRIBUTORS

Ramboll, VCS Denmark, Odense Renovation, ECT2 and Envytech Solution

LOCATION

Odense, Denmark

Dynamic overview helps mitigate H_2S challenges in sewer network

Danish water utility Aarhus Vand worried that high levels of hydrogen sulfide (H_2S) in the wastewater collection system in the village of Solbjerg were causing its sewer network to deteriorate at a faster rate than expected. Without a clear overview, the utility was unable to uncover the cause, magnitude or development of the issue.

In a joint effort, the company SulfiLogger installed 15 liquid-phase SulfiLoggerTM H_2S sensors measuring directly in the untreated sewage in strategic locations in manholes and discharge wells throughout the village. Connected to a cloud solution, all 15 sensors provided online H_2S data in real-time giving Aarhus Vand a reliable and dynamic overview of the situation in the entire village. Data showed that while the daily variations in H_2S remained similar, the magnitude of the daily H_2S peaks in a discharge well at the end of a force main from a nearby village varied significantly between 2 and 4 mg/L.

With solid data confirming Aarhus Vand's own suspicions of high H_2S levels being transported to the nearby village of Tranbjerg, the utility decided to install a newly-developed filter from Sulfinizer effectively eliminating the problem. The Sulfinizer filter system is a sustainable solution based on mussels' shells which converts H_2S into poorly soluble and unproblematic plaster.

CONTRIBUTORS

SulfiLogger, Sulfinizer and Aarhus Vand

LOCATION

Solbjerg, Denmark

CHAPTER 8

Tap into Danish water expertise

In Denmark, we value our water. We care for how we extract it, use it and release it back to nature. We consider water a valuable resource in the circular economy and a contribution to reaching our energy and climate goals. Above all, we value water for its potential to improve lives.

Let's protect our drinking water
Everyone deserves water that is clean and safe to drink. In Denmark, our drinking water is sourced entirely from groundwater. Our strategy is to protect our groundwater resources and in return, our drinking water only receives minimal treatment. Most waterworks simply pump, filtrate and distribute it to the consumers. We monitor it carefully and work to secure clean groundwater for future generations.

Let's care for every drop
Water is a scarce resource – and every drop counts. We must make the most of the water we have. In Denmark, we have low levels of water consumption. Benchmarking measures performed by DANVA based on major water utilities in Denmark show that the average Dane consumes just 100 litres a day, our water loss is less than 7 percent and our industries are increasingly focusing on water efficiency and reuse in their production. The price is based on full cost recovery, which ensures a reliable and efficient water supply 24 hours a day. Now let's fight to make every drop count worldwide.

Let's use our wastewater as a resource
Wastewater should no longer be thought of as a problem. Instead, let's turn our wastewater treatment plants into energy and resource recovery facilities, where we can extract phosphorous and produce organic fertiliser and biogas. In Denmark, we also aim to utilise wastewater even further up the value chain to produce products such as biofuels and bioplastics.

Let's move towards an energy and climate neutral water sector
Water plays a key role in creating a sustainable world. It is important to make sure our water management is sustainable as well. In Denmark, we use a minimum of energy to pump and treat water. We work continuously to be energy efficient and we contribute to a greener and more flexible energy system by producing energy from wastewater. In fact, some facilities are now producing more electricity than they consume. By 2030, the Danish water sector aims to be energy and climate neutral across the entire water cycle.

Let's use rainwater to create resilient and liveable cities
Rainwater can improve urban life if it is managed wisely. In Denmark, we store and delay rainwater and stormwater in parks, streets and football fields to create both resilient and liveable cities for a growing population. By doing so, we adapt to the changing climate and weather patterns as well as increase our biodiversity. So, while we may not be fans of rainy days, we appreciate what rainwater can do for us.

Let's swim in our city harbours
Water can be used actively in urban development. Waterfront areas and blue-green infrastructure can transform neighbourhoods and create economic growth. By treating our wastewater and managing our stormwater in underground basins, we have transformed polluted inner-city harbours into urban oases. So that when the weather permits, you can go swimming in the harbour in Danish cities.

Let's collaborate and solve the global water challenges
We want to connect, inspire and learn from each other in global partnerships – and work together to contribute to a more sustainable world. Water is one of our most valuable resources and it plays into many other agendas such as adapting to and mitigating climate change and increasing biodiversity. Through national and global partnerships across sectors, we can deliver on the UN Sustainable Development Goals on water and sanitation, affordable and clean energy, sustainable cities and communities and life on land and under water.

Water is life. And with the right care for water, we can make better lives.

From water treatment and supply to wastewater management and environmental conservation, the Danish water sector encompasses it all. Dive into our digital visualisation of Denmark's water value chain and discover companies and organisations that specialise in water-related technology, research and innovation.

Learn more about Danish water solutions, find more cases from around the world and connect with Danish water experts at:

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