ENGINEERING
TOMORROW

Application paper

Marselisborg: pathway to a **energy-neutral water sector**

300 Mt

annual CO_2e emission can potentially be avoided by applying best practice

The challenge

It takes tremendous amounts of energy to provide people with water and sanitation. This challenge will only increase as the world evolves and populations grow. Today, cost-effective and energy efficient solutions can reduce energy consumption in the water sector massively, not least at wastewater treatment plants.

Without action, the global water-related energy consumption will increase by 100% by 2030.[1]

The solution:
Turning wastewater plants into energy producers

In Aarhus, Denmark, the Marselisborg WastewaterTreatment Plant (WWTP) produces far more energy than it needs for treating wastewater for the 200,00 people it services. In fact, Marselisborg WWTP produces so much energy that it can cover the energy needed for the supply of drinking water as well. Marselisborg WWTP thus offers a pathway to an energy neutral water sector and shows how to decouple energy from water.

- The Marselisborg WWTP produces enough energy to cover the entire water cycle of a city area of 200,000 people – all with an estimated return on investment of 4.8 years.
- The surplus energy comprises electricity (50%) and heat (50%)

1. https://iea.blob.core.windows.net/assets/77ecf96c-5f4b-4d0d-9d93-d81b938217cb/World_Energy_Outlook_2018.pdf

Water is key to climate action
Harvesting the green potential in wastewater management

Water is essential. Most importantly as a precondition to life, but also as a key to combatting climate change. It takes tremendous amounts of energy to provide the public with access to clean drinking water and sanitation – a declared human right.

According to the International Energy Agency (IEA), the global water sector uses roughly 120 Mtoe per year, nearly equivalent to Australia's total energy use.[1] Without action, the global waterrelated energy consumption will increase by 100% by 2030.[2] The world needs more water and fewer carbon emissions. Energy efficiency provides a path to break the curve.

There is a significant potential for energy savings in the water sector if all the economically available energy efficiency and energy recovery potentials are exploited – not least within the water supply and water treatment sector.[3]

An obvious place to start is wastewater treatment plants, that are present in most cities around the world. Wastewater treatment plants are often operated by municipalities and eat up between 30-40% of municipal electricity bills.[4] For wastewater companies, the electricity bill constitutes the second largest operational cost behind labor.[5]

Wastewater contains significant amounts of embedded energy that can be harnessed to turnmwastewater management energy neutral, thus producing the same amount of energy that it consumes – and with the right approach even more. Consequently, wastewater treatment plants have the potential to be turned from energy consumers to energy producers.

2. https://iea.blob.core.windows.net/assets/77ecf96c-5f4b-4d0d-9d93-d81b938217cb/World_Energy_Outlook_2018.pdf
3. https://iea.blob.core.windows.net/assets/77ecf96c-5f4b-4d0d-9d93-d81b938217cb/World_Energy_Outlook_2018.pdf
4. https://www.epa.gov/sustainable-water-infrastructure/energy-efficiency-water-utilities
5. https://link.springer.com/article/10.1007/s11157-018-9478-x

Marselisborg Wastewater Treatment Plant Aarhus, Denmark

Owner: Aarhus Vand

Catchment area:
200,000 PE (People Equivalents)

Building profile:
More than 30 years old

Water and wastewater explainer

Energy for water treatment and distribution covers pumping up groundwater, treating of ground water to turn it into drinking water and pumping drinking water to the consumers in the catchment area.

Energy for wastewater transport covers the pump stations that pump wastewater from consumers in buildings to the WWTP.

WWTP covers all energy used at the wastewater facility

Energy-neutral water management for 200,000 people

Marselisborg Wastewater Treatment Plant

Wastewater treatment requires energy intensive processes that run all hours of the day. Energy is used to pump water through the sewers and down to the treatment plants, where vast amounts of energy are used in the aeration tanks, in the internal pump operation and in sludge treatment.

Wastewater treatment plants have great potential for producing energy, both in the form of electricity and heat. In the city of Aarhus, Denmark, the Marselisborg WWTP, which is operated by Aarhus Vand, has managed to reduce energy consumption while increasing energy production to an extent where they, on average, produce almost enough energy to match the catchment area's total water cycle, meaning both drinking water supply and wastewater treatment, thereby effectively decoupling water from energy.

The foundation of this achievement is a two-tier strategy: Reduce energy consumption while increasing energy production.

In 2005, Aarhus Vand began to improve energy efficiency and improve energy production at Marselisborg catchment area. Almost all equipment with a motor in the water cycle, 125 in total, were fitted with variable speed drives which offer the controllability that help secure just the right amount of energy needed for optimal performance. Control by these drives also contributes to a better sludge balance, improving energy production.

A series of online sensors are mounted throughout the WWTP. They provide critical information in real-time, which allows for automatic calculation of setpoints for the variable speed drives. As a result, the Marselisborg WWTP is a highly energy efficient operation.

But the Marselisborg WWTP is also a biorefinery that produces energy. In 2010, Aarhus Vand began to improve that side of the wastewater equation. The plant generates energy from the biogas it creates out of household wastewater. Sludge is extracted from the wastewater and pumped into digesters. These produce biogas – mostly methane – that is then burned to make heat and electricity.

In the period from 2016 and 2021, Marselisborg WWTP produced close to 100% more energy than needed for treating wastewater. The energy produced can be used to supply the area with drinking water as well. This means that Marselisborg WWTP produces enough energy to match the needs for the full water cycle of the entire catchment area, including both drinking water and wastewater, essentially decoupling water from energy. Process optimization and digitalization is estimated to have contributed to 70% of the improvements.

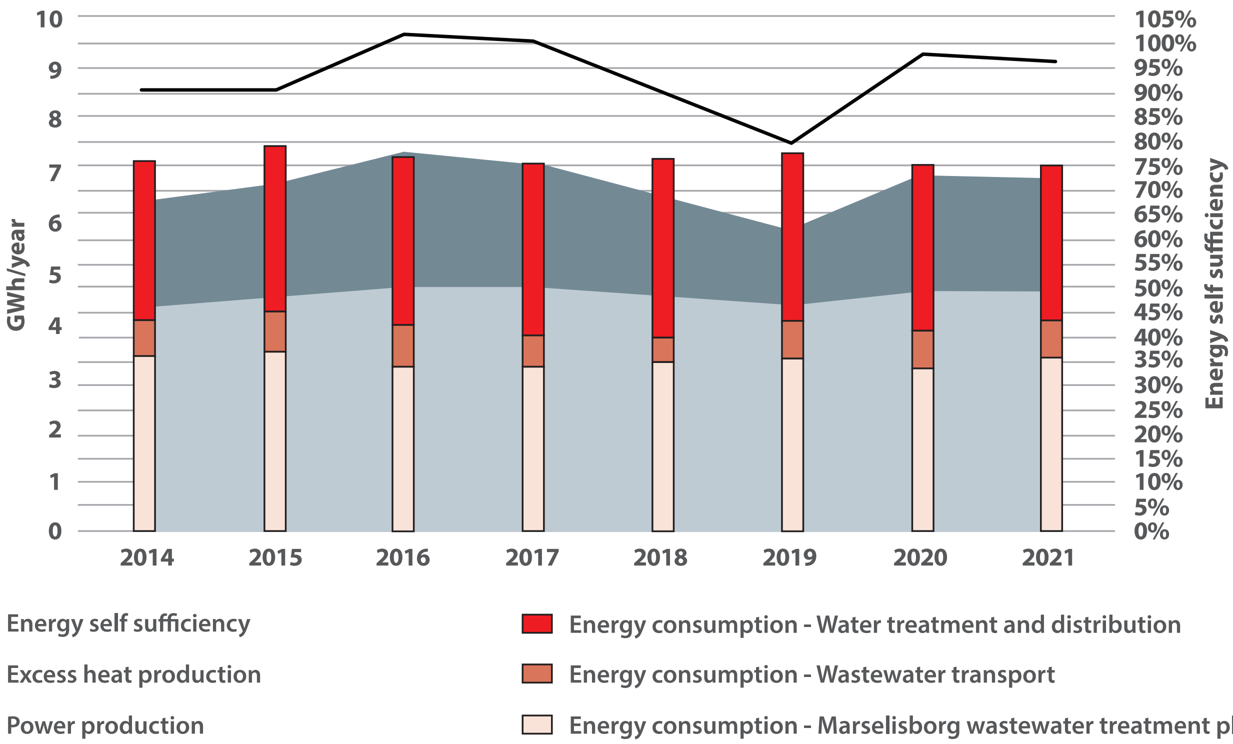
Decoupling water from energy

Viable with no supplements

The energy balance at Marselisborg catchment area averages 100% but fluctuates above and below this level throughout the seasons and the years. When generating power based on sludge, we need to set expectations at a realistic level: for these biologically based processes, with variable input volume, content, and occasionally unpredictable chemistry, natural variations in power production and energy consumption will always occur.

Although the biological energy generation processes are more complex than most people are aware of, they have been implemented at several wastewater treatment plants already, where they operate stably. Due to the complexity of the biology, it's not possible to copy the process directly from one site to the next; instead, an individual feasibility study is required for each new plant. These plants run very viably, and the established plants operating today have reached return on investment (ROI) for their process control equipment within 3 years.

It's important to note that the facility receives no energy from solar or wind installations. Neither is it supplemented with fat, oil and grease (FOG) from the food industry, nor sludge from other facilities. The wastewater inflow is from a combined sewage network system. All the energy generated at Marselisborg WWTP comes from normal household wastewater, which represents 90% of incoming load.



Energy production from Marselisborg WWTP almost covers the entire water cycle

Energy consumption	2016-2021 Average
Water treatment, distribution (kWh)	3.3 mill
Wastewater transport (kWh)	0.7 mill
Marselisborg WWTP (kWh)	3.3 mill
Total energy consumption (kWh)	7.2 mill
Energy production	
Electrictiy production (kWh)	4.7 mill
Heat production (kWh)	2.1 mill
Total energy production (kWh)	6.8 mill
Own energy supply degree	
Wastewater treatment process, electricity and heat (%)	208%
Total water cycle, Marselisborg catchment area	94%

Average return on investment for process control equipment is estimated at

3 years

From energy consumer to energy producer
A guide to efficient water treatment

The Marselisborg WWTP provides a pathway towards an energy neutral water sector for cities around the world. In simple terms, two steps are required: Refrain from using energy that is not needed and use the energy embedded in the wastewater.

1. Define the baseline

Measure
Energy meters show how much energy is used both for water supply and wastewater treatment.
Evaluate
Find the most attractive energy saving opportunities.

2. Reduce energy consumption

Local digitalization
Implement local control loops by installing real-time sensors and variable speed drives where there is potential to secure a more efficient use of energy.

Efficient components
Switch to more efficient components, e.g., high-speed turbo blowers.

Holistic digitalization
Combine local control loops in a holistic, automatic, and real-time process based on digital process control of the whole facility.

3. Increase energy production

Holistic digitalization
Selecting the right process control to obtain energy savings creates a double effect. Energy is saved and more sludge is available for gas production, which can be turned into electricity or heat through the process of co-generation (CHP).

Taarnby WWTP

In Taarnby Municipality within Greater Copenhagen, a new energy central provides both district cooling- and heating to businesses and citizens. Uniquely, the energy central utilizes excess heat from the nearby WWTP to provide heating in the winter and cooling in the summer. The excess heat is extracted by four large heat pumps and results in reduced costs, reduced energy consumption and reduced emissions.

The symbioses between excess heat from the WWTP, district heating, district cooling and the electricity grid is the perfect example of sector coupling: Re-using and recycling energy by linking systems and end-use sectors.

Heat pumps can recover the heat embedded in wastewater outlets. The temperature of the outlet water from the wastewater facility will typically be 7 – 9 °C higher than in the receiving water, improving heat pump efficiency and securing shorter payback time. The excess heat can be exported to neighboring buildings or into the local district heating system, an example of sector coupling.

Source: https://dk.ramboll.com/medier/rdk/varmepumper-paa-spildevand-giver-baade-fjernkoling-og-varme-i-taarnby

Sector integration increases the potential in wastewater

Providing heat and hot water to buildings requires nearly half of global final energy consumption,[6] much of which comes from coal, oil, and natural gas.[7]

In many parts of the world, district energy systems supply homes and companies with heating as well as cooling. District energy systems taps heat from processes, such as at power plants, and distribute it through pipelines to end-users in the form of water. District energy is a collective system that supply an entire area with heating or cooling. There are vast district energy systems in China, Russia and Europe and more are coming.

Today, the majority of global district heat production relies on fossil fuels.[8] According to the International Energy Agency (IEA), the world needs to increase the share of green sources in district heating from 8% today to about 35% in 2030. If we succeed, this will help to slash carbon emissions from heat generation by more than one-third.[9]

The solutions are already here, to meet that goal and more.
Denmark is one of the world's most energy-efficient countries, and the widespread use of district heating is one of the primary reasons.[10]
In Denmark, 65% of households cover their demand for heating with district heating and more than 70% of the heat is from green sources such as waste, biomass, wind and excess heat from various commercial processes.[11]

Sønderborg Municipality in Denmark is no exception. Since 2007, carbon emissions from space heating and domestic hot water have dropped by 73% since 2007 and the local district energy systems have been key drivers. As an added bonus, the share of natural gas-fired district heating has been reduced from 70% to 8% today.[12]

One of the main strengths of district energy systems is their capacity to integrate different heat sources that can push fossil fuels out of the heating and cooling mix. As a result of improved energy efficiency temperatures in the district energy systems have been lowered over time, which allows for even more green sources to be introduced into the system.[13]

That includes excess heat, not least from WWTPs that have a huge potential. According to the Danish Water and Wastewater Association (DANVA), the potential in excess heat from wastewater treatment plants in Denmark, a country of 5.8 million inhabitants, corresponds to 600-700 MW. That's the equivalent of two fairly large power plants,[14] meaning a potential to heat about 20% of all households with carbon neutral heat.

With these insights, it's clear to see that excess energy from the water industry can contribute significantly to the energy supply required for district heating. In this way, energy generated in wastewater treatment can powerfully reduce the reliance of district heating upon fossil fuels.

6. https://www.iea.org/fuels-and-technologies/heating
7. https://www.iea.org/fuels-and-technologies/heating
8. https://www.iea.org/reports/district-heating
9. https://www.iea.org/reports/district-heating
10. https://ens.dk/en/our-responsibilities/global-cooperation/experiences-district-heating
11. Fakta om fjernvarme (danskfjernvarme.dk)
12. ProjectZero: Monitoring report 2020 Sonderborg municipal territory
13. https://vbn.aau.dk/ws/portalfiles/portal/280710833/1_4GDH_progression_revised_May2018.pdf
14. https://www.danva.dk/viden/danskvand-temaer/vand-og-klima/flere-udnytter-varmen-i-spildevandet/

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Reducing energy use for water is possible all over the world

Today, over 60% of the global population lacks access to safely managed sanitation, and just 20% of wastewater is treated. Meeting the UN's sustainability goal on water and sanitation (SDG 6) to provide clean water and sanitation for all constitutes a serious challenge. Meeting that goal has a significant impact on a municipality's energy expenditure but also on efforts to combat climate change. Carbon emissions from untreated wastewater are about three-times higher than what conventional wastewater treatment plants generate when treating wastewater.[15]

The Marselisborg WWTP provides a blueprint for how to turn a wastewater facility into an energy positive enterprise, thus producing more energy than it needs. If other cities prioritize the new WWTP facilities needed to meet the UN's sustainability goals, it could result in energy savings of up to 650 TWh globally. That saving exceeds the total energy produced by all coal power plants in the EU.[16] Potentially, 300 Mill t CO_2e emission can be avoided by applying the best Danish practice, equivalent to best available techniques (BAT) globally.

15. UN stats (2020). Ensure availability and sustainable management of water and sanitation for all.
16. https://iwa-network.org/how-can-more-water-treatment-cut-co2-emissions/