WHITE PAPERS FOR A GREEN TRANSITION

Wastewater

Highlight publication • Water Technology Advisory EU

INSIDE THIS HIGHLIGHT PUBLICATION

Urban wastewater treatment and its potential for the city

Wastewater as a source of clean energy

Resource recovery from wastewater

WASTEWATER
Highlight publication • Water Technology Advisory EU

Version 1.0
December 2023

FRONT PAGE PHOTO
Stiig Larsen
Editing: Henrik Wedel Sivertsen

EDITOR
State of Green

EDITORIAL PARTNER
Water Technology Advisory EU

CONTRIBUTORS

Chapter 1
Author Peter Underlin, Hillerød Forsyning
Case: Varga (DK)
Case: Solrødgaard (DK)

Chapter 2
Author Aarhus Water Per Overgaard Pedersen
Case: NISSEN energy Inc. Thorvald Pedersen
Case: Aarhus Water Per Overgaard Pedersen

Chapter 3
Author VCS Denmark Per Henrik Nielsen
Case: Herning Vand PhosporCare
Case: Billund Vand Thomas Kruse Madsen

DOWNLOAD THIS WHITE PAPER
Download this white paper and other related publications
at www.stateofgreen.com/publications

FOR MORE INFORMATION
To order copies of this white paper or receive information about other
related publications, please contact State of Green at info@stateofgreen.com

Funded by
the European Union

No. 001
KLIMA-NEUTRAL
TRYKSAG

CERTIFIED
cradle to cradle
SILVER
PurePrint® by KLS
Produceret bionedbrydeligt
af KLS PurePrint A/S

FSC
www.fsc.org
MIX
Papir fra
ansvarlige kilder
FSC® C022933

Index

CHAPTER 1

Urban wastewater treatment and its potential for the city

Globally, 80% of all wastewater is neither collected nor treated adequately. This poses a significant negative impact on both environment and human health. Combined with new challenges from a changing climate, urban wastewater management must move from wastewater treatment to resource and energy recovery.

Urban population growth means wastewater treatment plants (WWTPs) must treat an increasing volume of wastewater in order to secure the health of the local population and water environment. It is important that both large centralised and small decentralised plants can discharge the treated wastewater without harming the recipient, whether it is the sea or a small stream.

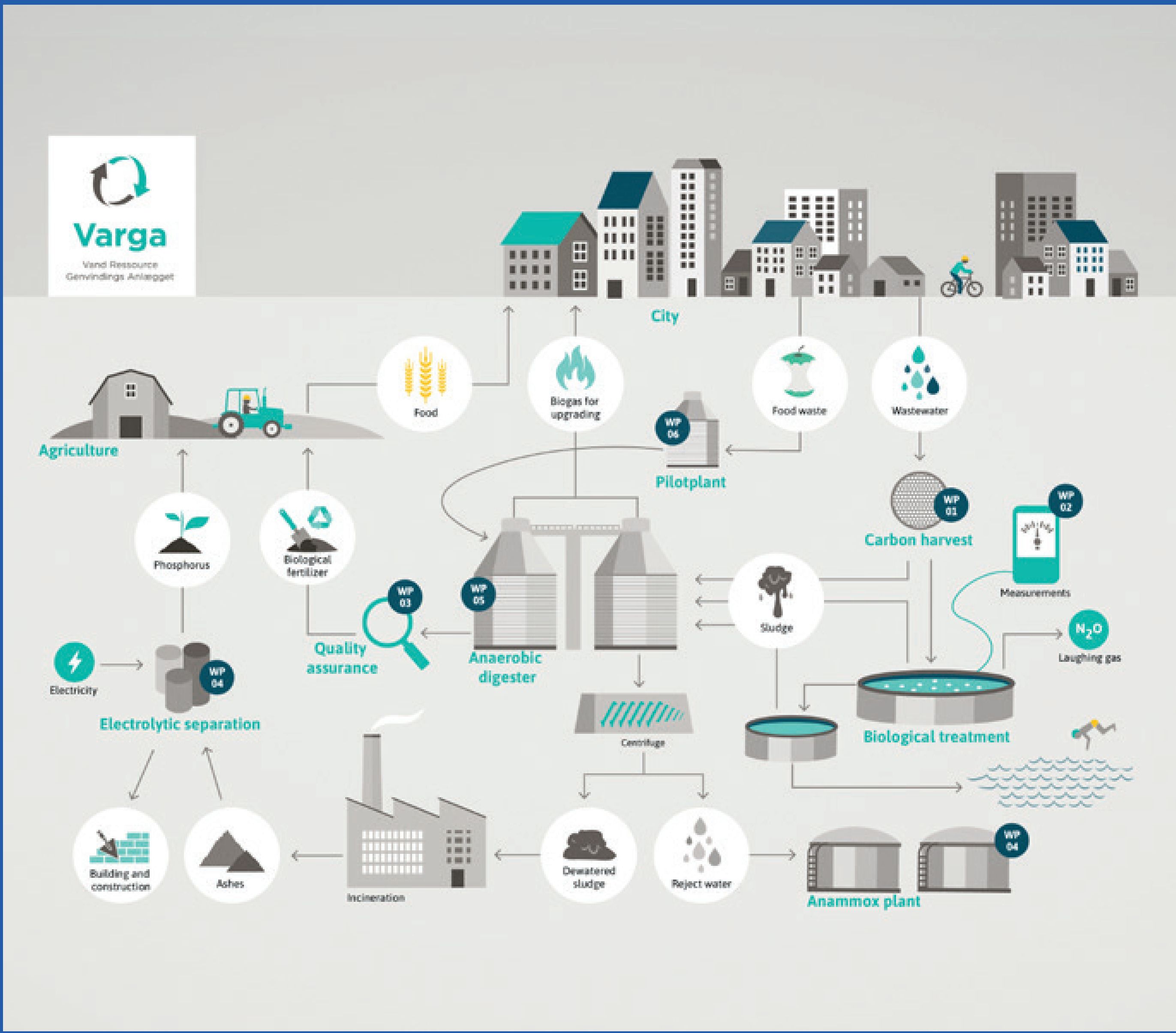
Danish WWTPs operate under strict requirements for improved treatment of wastewater. The wastewater sector has spent many years refining and developing technologies that treat wastewater to a high level (through primary, secondary and tertiary treatment) to ensure that it does not contaminate the recipients. Combined with a taxation system which incentivises WWTPs to treat the wastewater beyond the legal requirements, this has resulted in outlet concentrations which contain far less discharged material (only 20-70 % compared to the legal limits), according to a study from the Danish Water and Wastewater Association (DANVA).

Liveable cities depend on successful wastewater management
Sewage collection and treatment systems play a key role in creating liveable cities where recreational activities are possible along the city's harbours, lakes, or rivers. In Denmark, blue-green cities, harbour baths and other recreational facilities would not have been possible without well-managed wastewater infrastructure. Climate change is putting increasing pressure on wastewater infrastructure in cities around the world. A common challenge is to ensure sufficient capacity in the sewer systems to prevent overflows, especially in times of heavy rain. When redesigning the wastewater infrastructure, focus should also be on separating and treating stormwater from roads and other contaminated surfaces to prevent pollution.

Powering the city through energy recovery
In alignment with the country's overall green transition strategy, the Danish water sector aims to become energy and climate

neutral by 2030. To fulfil this ambition, a green conversion of the wastewater sector is currently taking place in Denmark. The starting point has been to focus on energy efficiency and energy recovery. Today, several plants are now net producers of energy, where the sludge is used to produce biogas and electricity and excess heat is used in the district heating system. Recovery of energy by using heat pumps is also a new area for innovation and development.

From wastewater treatment to resource recovery
In the future, wastewater treatment needs to be designed in a way which allows for not only energy but also other resources (e.g., phosphorous) to be extracted and included in the circular economy while also ensuring that harmful substances do not reach the recipient. Considering wastewater as a resource is a relatively new perspective and new knowledge and technology is still needed to recover valuable resources in the wastewater on a commercial scale. Research and development in Denmark is dedicated to this field. Advanced membrane technology is already undergoing rapid development, but new specialised technologies are still needed. Sorption technology that enables collection of low concentrations of valuable substances or pollutants will also have a prominent place in the future WWTP. For instance, new bacterial cultures need to be developed to produce base chemicals etc. WWTPs can be seen as production lines, where usable substances e.g., phosphorus and ammonium are removed along the way and other products are removed and further processed e.g., organic matter to produce biogas or base chemicals which can be used for high priced products in the pharmaceutical industry etc. Furthermore, wastewater from industries must be carefully reviewed to ensure that valuable components are separated. Of course, not all substances in the wastewater can be recovered as some will still need to be removed and degraded for the sake of the purity of the products and the discharged wastewater.



WWTP contributes to circular economy in the urban water cycle

Wastewater treatment can contribute significantly to the implementation of circular economy principles in the urban water cycle of Greater Copenhagen. A new project - VARGA – aims to transform the traditional treatment plant Avedøre WWTP (350,000 PE) into a Water Resource Recovery Facility, by implementing several innovative technologies within wastewater treatment, nutrient recovery, and greenhouse gas reduction. Major elements in the project include prefiltration in full scale, P-recovery in pilot scale and active reduction of N_2O. As part of the project, a Life Cycle Assessment and an eco-efficiency analysis has been conducted. Initial results show that the Total Added Value is higher after implementing the VARGA concept compared to business as usual – without compromising the treatment efficiency. Circular economy is central for the project and the experiences gained further contribute to the Danish national goal of an energy and climate neutral water sector in 2030 as well as the UN agenda on sustainable development.

CONTRIBUTORS

BIOFOS, EnviDan, Unisense Environment, ARC and DTU Environment with financial support from the Danish Eco-Innovation Programme

LOCATION

Copenhagen, Denmark

Solrødgård – a fully covered WWTP designed in harmony with nature

The old WWTP in Hillerød was challenged by a growing city and complaints about bad smell and noise. Building a new traditional plant outside the city would simply cause the problem to reoccur in 30 years. Instead, a 100 % covered WWTP was built in a 52-ha area 4 km from the city centre. The new 'Solrødgård Climate and Environment Park' is home to all of the utility's activities; district heating, waste, water and wastewater. All processes are encapsulated and equipped with advanced DIMS control systems, which provides maximum control of odour and nitrous oxide emissions. Surplus energy goes to the district heating grid and helps displace fossil fuels. The vision was to draw inspiration from nature's integrated systems where everything is produced from renewable energy sources. The plant's exit strategy is to leave a well-functioning wetland in 40-60 years' time, where the biological and recreational aspects are strengthened compared to today. The master plan is designed with respect for the surrounding nature with the functional areas as 'pockets' in this contiguous landscape. A new neighbouring district is under development with a hospital, railway station and 5000 homes and businesses. Real estate prices are up to 30 % higher than if the plant had been a traditional WWTP.

CONTRIBUTORS

Hillerød Forsyning, Krüger, Stjernholm, DHI, WSP, Gottlieb Paludan Architects and Henning Larsen Architects

LOCATION

Hillerød

CHAPTER 2

Wastewater as a source of clean energy

Reducing the costs for collection and treatment of wastewater is an important issue for water utilities around the world. To achieve reductions, focus must be on cost efficiency, improvement of the wastewater treatment plants' energy self-sufficiency and possible sale of surplus energy to the grid. In Denmark, this means heading for energy producing wastewater treatment plants and an energy neutral water cycle.

On a global level, the International Energy Agency (IEA) estimates that the water sector accounts for approximately 4% of the world's total electricity consumption and wastewater treatment alone accounts for a quarter of this. Meeting the UN's target of halving the proportion of untreated wastewater by 2030 could therefore put significant upward pressure on energy demands, unless energy efficiency and recovery technology is applied at the treatment facilities. In Denmark, the water sector's share of the country's total electricity consumption has fallen to 1.9% as more and more utilities have realised the great potential for energy savings and energy recovery in wastewater treatment. Most wastewater treatment plants (WWTP) in Denmark have invested in an assessment of different ways to reduce their energy consumption. These include implementation of online monitoring and energy management systems, replacement of surface aeration by more energy efficient bottom aerators and different operational approaches.

New focus towards energy self-sufficiency

In the recent years, Danish water utilities have moved beyond simply focusing on reducing energy consumption to also focusing on energy production. The first goal is typically to become energy neutral, and the second goal is being able to sell excess electricity and heat to the local electricity and heating companies. Some of the largest water utilities are already well on their way. In Denmark's second largest city, Aarhus, the Marselisborg WWTP produced 30% more electricity than the amount consumed by the plant itself on average between 2015-2019. At the same time the treatment plant produced 75% more heat than it consumed, resulting in a total net energy production of 150%. In Odense the Ejby Mølle WWTP achieved similar levels of total net energy production. As a next step, the water utilities in both cities are now looking into recovering the heat from the wastewater before it is discharged with the additional benefit of reducing the temperature impact on the receiving waters.

"Danish water utilities will contribute to Denmark's goal of 70 % CO_2 reduction in 2030 through energy recovery and a significant reduction of energy consumption from wastewater treatment. At Aarhus Vand, we have reduced our GHG emissions by nearly 80 % since 2008. This shows that there are great benefits to be gained by working systematically with energy optimisation." Lars Schrøder, CEO, Aarhus Vand and Vice Chairman of the Danish government's Climate Partnership on Waste, Water and Circular Economy.

Solutions depend on plant design and context
More and more WWTPs in Denmark are upgraded with anaerobic digestion of sludge and/or co-digestion with organic waste products and they utilise the produced biogas to generate electricity and heat. The optimal solutions depend on the individual plant design and the possibilities for either internal use or external sale of the produced electricity or heat. The tipping point for which the implementation of anaerobic digestion is financially viable depends on the development of new technologies and changes in the price structure for purchase and sale of electricity and heat. In Copenhagen, a technology is currently under implementation which allows for upgrading biogas to a quality which is similar to natural gas or vehicle fuel.

Heading for an energy and climate neutral water cycle
By introducing new technologies to reduce energy consumption and improve energy production, it is the goal that the utility companies can provide an energy neutral water cycle. In this scenario, the energy production from the utility's treatment plants is able to cover the energy consumption related to its groundwater extraction, water treatment, water- and wastewater transport as well as wastewater treatment. In 2019, VCS Denmark demonstrated a 100% net energy production for the water cycle in the entire service area for the utility, covering all 8 WWTPs and the production and distribution of water in the City of Odense, Denmark's third largest city with a population of 200,000. The Danish water sector has set a common goal of becoming energy and climate neutral by 2030. In 2020, this goal was implemented in the government's national climate plans.

Benchmarking and innovation lead to lower costs
The innovation of new wastewater treatment optimisation and cost-efficient solutions for both the construction and operation of infrastructure is largely driven by the fact that Danish water utilities are subjected to mandatory benchmarking on operational parameters and cost efficiency across the water sector. Innovation projects are often based on collaboration across governmental bodies, water utilities, consulting companies, technology suppliers, universities and research institutions. The Danish Water and Wastewater Association (DANVA) also carries out its own voluntary benchmarking each year.

Achieving 150% energy self-sufficiency

Over the past five years, the water utility Aarhus Vand has put great focus on energy savings and energy production. At its Marselisborg WWTP, the utility has implemented energy-saving technologies such as an advanced SCADA control system, a new turbo compressor, sludge liquor treatment based on the anammox process, as well as optimised the fine bubble aeration system. This has resulted in a reduction in power consumption of approximately 1gwh/year which corresponds to about 25% in total savings. During the same time period, the energy production has been improved through implementation of new energy efficient biogas engines (CHP), resulting in an increase in electricity production of approximately 1 gwh/year. Furthermore, a new heat exchanger has been installed with the aim of selling surplus heat to the district heating grid, which represents approx. 2 gwh/year. Between 2015 and 2019, Marselisborg WWTP had an average total energy production of 9.6 mwh/year and an energy consumption of 6.4 mwh/year, equivalent to a net energy production of 150%. Most of the installed technologies have a payback time of less than 5 years.

CONTRIBUTORS

Aarhus Vand

LOCATION

Aarhus

Energy positive operations at Downers Grove WWTP

The Downers Grove Sanitary District in Illinois has dedicated significant resources to reduce its energy footprint. Improvements in process efficiency including plant automation, aeration system improvements, upgrades to HVAC and building management systems, and variable frequency drives have resulted in a 30% reduction in electricity usage at its wastewater treatment plant. The remaining electricity used by the facility is produced on-site using a biogas driven combined heat and power system. Biogas is produced by co-digesting hauled food waste and sewage sludge generated on-site. The biogas is used as fuel to drive an engine-driven electric generator. Furthermore, heat recovery in the form of circulating hot water is used for plant process heat. The CHP plant was installed in 2017 with a payback time of 3.5 years. Total Infrastructure investments of roughly USD 5 million are expected to have a 10-year payback period. In 2021, the plant produced enough energy to supply its own operations, and feed energy back to the grid.

CONTRIBUTORS

NISSEN energy Inc., Landia and Downers Grove Sanitary District Wastewater Treatment Center

LOCATION

Illinois, USA

CHAPTER 3

Resource recovery from wastewater

Traditionally, wastewater has been considered a liability, meeting increasingly stricter standards for wastewater discharge with increases to the costs of treatment. Utilising the resources in the wastewater can prove an important step in the opposite direction, considering wastewater treatment plants as resource recovery facilities.

Considering wastewater as a resource is a relatively new perspective. However, today it is widely recognised that the organic content in the wastewater can be a resource for energy production, the nutrients - especially the phosphate – can be used for fertiliser production, and the water itself can be cleaned to such high standards that it can be reused in a number of ways – e.g. for flushing toilets or laundry machines.

Utilising organic content
As described in the previous chapter, organic material in wastewater can be separated and utilised for biogas. This has been standard procedure in larger wastewater treatment plants for a while, and new water treatment technologies and more efficient equipment for combined power and heat production have increased the potential. Organic content can be saved for energy use in biogas production if new carbon saving processes for nutrient removal are introduced. Denmark has vast experience in optimising the use of carbon and is now also gaining know-how in nutrient recovery.

Phosphorus recovery from wastewater sludge
Phosphorus is a scarce resource with great value for the agricultural sector. Phosphorus is accumulated in the wastewater sludge and in internal side streams and if treated properly, it is possible to change this into a controlled harvesting of a pure fertiliser. The recovery of phosphate for fertiliser enables a multitude of possibilities for sludge handling, not wasting the valuable phosphorus to end up in low quality form as ashes or mixed with heavy metals and micro pollutants from wastewater in the sludge. The phosphorus product struvite has been approved in Denmark as a fertiliser product. Two full-scale plants in Aarhus currently forms the background to increase the current P-recycling from approximately 15% to 25%. Once these are completed, the total phosphorus recovery throughout the catchment area is expected to be increased to approximately 22 tonnes P/year or approx. 0.5 tonnes of struvite fertiliser per day.

Benefits of using struvite fertiliser compared to sewage sludge
The solution of recovery of struvite as a pure mineral phosphorus fertiliser offers several advantages in comparison to the application of sewage sludge on agricultural land:

- **Environmental benefits: Struvite is significantly cleaner than the sewage sludge in terms of heavy metals. The content of the typical problematic metals such as lead, cadmium, nickel, chromium copper and zinc is a factor of 20-100 times lower in relation to the content of phosphorus.**

- **Reduced risks of groundwater contamination: Phosphorus from wastewater can be utilised for agriculture without risking a contamination of soil and groundwater with the accumulation of heavy metals and other harmful substances to the environment, which makes it possible to carry out subsequent groundwater exploitation in the same area.**

- **Greater flexibility in terms of usage and storage: Struvite is much more flexible as a fertiliser as the material is concentrated, comes in a dry form and is possible to store for longer periods of time.**

- **Economic benefits: Struvite can be sold at a high price (up to EUR 335 per tonne)**

- **Ready-to-use as fertiliser: There is no need for further processing as the material is ready to use and can be mixed with other mineral fertilisers if there is a need for changing the level of potassium or nitrogen.**

- **Better suited as dedicated fertiliser: Struvite has shown excellent properties for fertilising specific plants and crops with need for extra phosphorus and magnesium. Golf courses and plant nurseries are good examples of this.**

- **Low solubility: Struvite has a low solubility, making it suitable for depot fertiliser where the phosphorus content is released slowly in line with the needs of the plants. This is an advantage for fertiliser spreading without danger of dissolution into groundwater or surface water.**

- **Lower cost: Sludge from P-recovering plants, which is low on phosphorus, can be used as a bio-fuel without it resulting in a loss of phosphorus to ashes. The cost of regaining phosphorus from ash is much higher than extraction as struvite from wastewater.**

Struvite based P-recovery is the state-of-the-art for phosphorus recovery from wastewater. The technology is still under development and Danish wastewater utilities and companies are working on developing even more efficient process solutions.

Phosphorus recovery from wastewater

In 2015, the water utility Herning Vand Ltd. Opened the second P-recovery plant in Denmark, which recovers phosphorus from a concentrated side stream in the wastewater treatment plant. For several years, the WWTP suffered from struvite scale build-up in its sludge and wastewater pipes, causing problems for the dewatering process of sludge and biogas production. In addition to solving the problem, Herning Water wanted to exploit the potential of recycling the struvite into agricultural fertiliser. A solution based on controlled precipitation of struvite was therefore designed, and a full-scale recovery plant of the phosphorus compound struvite was built based on previous test results from Aarhus Vand at its plant Aaby WWTP. At both plants, the struvite is precipitated as a 'ready-to-use fertiliser' and sold to a fertiliser company. An official approval of the product as commercial fertiliser has been obtained for the struvite produced at both the Herning and Aarhus plants under the name Phosphorcare™. The operational savings at the treatment plants and the expected revenue from sale of struvite is expected to result in a payback time of 10-12 years.

CONTRIBUTORS

Herning Vand, Aarhus Vand, Stjernholm, Grundfos, Norconsult, Suez and SEGES

LOCATION

Herning and Aarhus, Denmark

Resource recovery for the future

Billund Biorefinery (BBR) is a resource recovery plant that integrates waste management and wastewater treatment. BBR produces clean water, energy for the local public district heating and power grids, as well as high quality natural fertiliser for the surrounding agricultural areas. The wastewater catchment areas consist of combined and separate sewer systems and the waste comprises of sorted organic waste from households and local industries. BBR integrates wastewater treatment with anaerobic digestion and other innovative processes like Exelys™ (thermal hydrolysis) and Anitamox™ (Anammox process). These, along with STAR™ advanced online monitoring and control system, minimises energy usage and maximises energy production and effluent quality. As a result, effluent nutrient concentrations (N, P and COD) have been reduced to a quarter of the level required by Danish legislation and the plant operates with a 200% energy surplus relative to the plant's own consumption. BBR is a public private partnership and was financially supported by the Danish Eco-Innovation Programme (MUDP) and the Danish Water Sector Foundation (VTUF).

CONTRIBUTORS

Billund Vand og Energi A/S and Krüger Veolia A/S

LOCATION

Billund, Denmark

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

www.stateofgreen.com

STATE OF GREEN IS A NOT-FOR-PROFIT, PUBLIC-PRIVATE PARTNERSHIP FOUNDED BY:

Danish Industry

Danish Agriculture & Food Council

GREEN POWER DENMARK

Ministry of Industry, Business and Financial Affairs

Danish Ministry of Climate, Energy and Utilities

Ministry of Environment of Denmark

Ministry of Foreign Affairs of Denmark