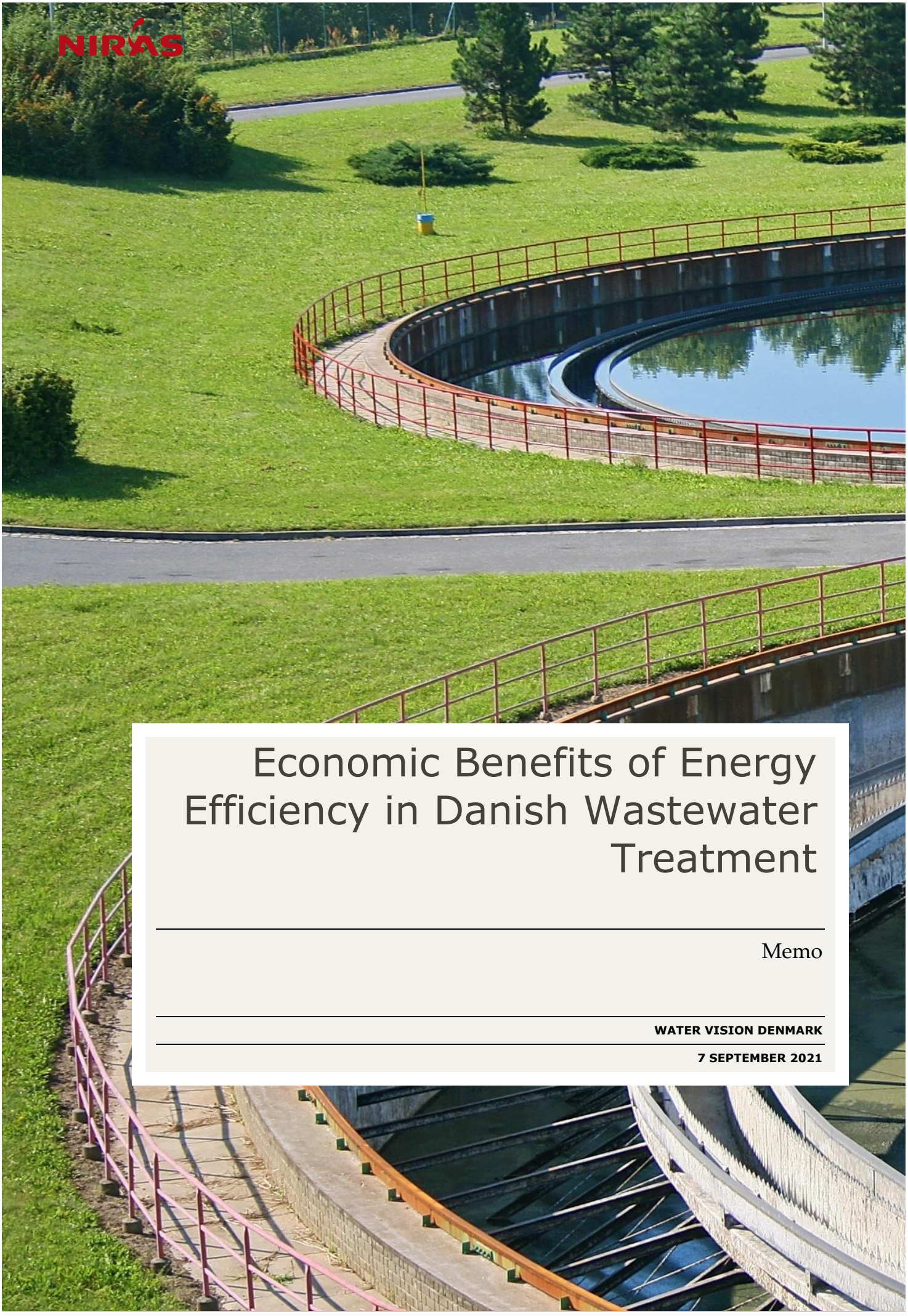

Economic Benefits of Energy Efficiency in Danish Wastewater Treatment

Memo

WATER VISION DENMARK

7 SEPTEMBER 2021

Contents

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1 Introduction

Energy consumption and energy efficiency is globally a key focus area – also in the water sector: According to the International Energy Agency's *World Energy Outlook* from 2018[1], the water sector accounted for 4 % of the total global electricity consumption, a quarter of which wastewater treatment is to blame. However, the Danish water sector is punching above its weight as the sector only accounts for 1.4 % of the country's total electricity consumption[2]. Moving towards a more sustainable use of energy in the water sector and reducing the greenhouse gas emission from the sector is important to strive for to deliver reductions to the Paris Agreement and to contribute to the UN Sustainable Developing Goals.

The partners cooperating in Water Vision Denmark include private sector organisations and the Ministry of Environment of Denmark[3]. Water Vision Denmark promotes innovation, energy and climate neutrality as well as export and implementation of energy efficient water technologies internationally. During the last 5-10 years, Water Vision Denmark has worked towards energy- and climate neutrality in the Danish water sector and in 2020 the Danish Parliament supported this goal by deciding that the water sector must be energy- and climate neutral by 2030.

The water sector in Denmark is in many ways unique, also when it comes to wastewater treatment. The wastewater treatment plants (WTPs) in Denmark have adopted some of the best technologies in the world, technologies that not only enable the plants to treat the wastewater but also to use it as a resource and treat it (energy)efficiently.

In this memorandum three leading wastewater utilities and wastewater treatment plants in Denmark are presented. Examples of energy saving initiatives at the three plants are presented; initiatives that are already implemented with remarkable results, one must note. Each initiative is presented with a short introductory note, an overview of the achieved energy savings, the economic costs and savings as well as an approximate payback time.

The three utilities and their wastewater plants are: VCS Denmark and Ejby Mølle wastewater treatment plant, Biofos Denmark and Avedøre wastewater treatment plant and finally Aarhus Vand and Marselisborg wastewater treatment plant.

[1] Source: https://www.iea.org/commentaries/the-energy-sector-should-care-about-wastewater
[2] Source: Calculated based on the water sector's consumption of electricity from 'Performancebenchmarking 2019' (published by the Danish Environmental Protection Agency) and the total national electricity consumption stated in the national Danish energy statistics, 'Energistatistik 2019' (published by the Danish Energy Agency)
[3] The partners in Water Vision Denmark are: Confederation of Danish Industry (DI), The Danish Environment Technology Association (DETA), DI Water, DANVA - Danish Water and Wastewater Association and the Ministry of Environment of Denmark

2 Summary - Energy savings at Danish WTPs

The growing global energy consumption and increasing concentration of greenhouse gases (GHGs) in the atmosphere have highlighted the need to achieve energy savings and increase energy efficiency rapidly. For more than a decade, the Danish water sector has had a persistent focus on energy savings and to increase energy efficiency and energy production in a cost-effective manner.

In the following, some of the energy saving initiatives and achievements of three leading wastewater utilities and wastewater treatment plants (WTPs) in Denmark are introduced. The three utilities and their wastewater plants are: VCS Denmark and Ejby Mølle wastewater treatment plant, Biofos Denmark and Avedøre wastewater treatment plant and finally Aarhus Vand and Marselisborg wastewater treatment plant.

For each energy saving initiative, an overview of the achieved energy savings, the economic costs and savings as well as an approximate payback time are presented[4].

2.1.1 VCS Denmark, Ejby Mølle wastewater treatment plant

Continuous optimization of the wastewater treatment at Ejby Mølle wastewater treatment plant has led to the plant now being a net producer of energy and the achievement of an energy self-sufficiency percentage of 180.

The results from the renovation of a pump station, replacing older boilers with an energy efficient model and the installation of two heat pumps at Ejby Mølle and Bogense WTPs are summarized in the table below:

Technology/ project	Capital Investment* (Mio. DKK)	O&M costs* (DKK/year) (Mio. DKK)	Payback time** (years)	Energy savings*** (MWh/year)	Emission Reduction**** (ton CO_2e/year)
Renovation of pump station	-	-	-	11.6	2.2
Replacement of old boilers	-	-	-	235	-
Heat pumps (Ejby Mølle)	99	1.5	10	709,071	6442
Heat pumps (Bogense)	0.04	-	3.5	25	4.7

* Current prices
** Calculated simple payback time
*** Different types of energy
**** Only emission reductions related to energy savings. Emission factors from virksomhedsguiden.dk or stated in the draft project approval

In the table, the payback times for the heat pump solutions are between 3.5 and 10 years. The energy savings from the different initiatives vary and the emission reductions from the energy savings vary accordingly. However, reductions in GHG-emissions have been calculated for three out of four of the highlighted initiatives.

[4] Some projects were implemented several years ago and not all information is available to the desired level of detail. If data is not measured or for some other reason not available, a dash ('-') is presented in the summary table.

2.1.2 Biofos, Avedøre wastewater treatment plant

The wastewater treatment plant in Avedøre which is owned and operated by BIOFOS, is being transformed to a 'Water Resources Recovery Facility'[5]. The aim is to become 'Climate positive' in 2025 and from then on reduce CO_2e-emissions further. The facility at Avedøre already produce and upgrade a considerable amount of biogas based on sludge from the wastewater. The upgraded biogas – biomethane – is let into the natural gas grid system.

The results from installing bottom aeration and a new inlet pump station are summarized in the following table[6].

Technology/ Project	Capital Investment* (Mio. DKK)	O&M costs* (Mio. DKK/year)	Payback time** (years)	Energy Reduction (MWh/year)	Emission Reduction (ton CO_2e/year)
Bottom aeration[7]	49	3.7[8]	26.5	1,940	-
Inlet pump station[9]	29	-	-	-	-

* Current prices.

** Calculated simple payback time

The payback time for bottom aeration is more than 25 years but it should be noted that at the time of implementation, this technology gave substantial tax benefits which made the technology more profitable and reduced the payback time. Another point of attention is that at the time of the investment, the energy prices were higher and thus the payback time shorter.

2.1.3 Aarhus Vand, Marselisborg wastewater treatment plant

At Marselisborg wastewater treatment plant, Aarhus Vand has introduced a number of initiatives to reduce energy consumption and increase energy production. One of these initiatives is implementing an advanced control system which provides energy reductions through online control and optimization of processes. Another initiative is replacing outdated and inefficient blowers with a highly efficient ABS HST compressor and the installation of new membranes in the bottom aeration system. This increases the efficiency of the aeration and reduces the energy consumption as well as CO_2-emissions. A third initiative is the introduction of a side-stream Anammox sludge liquor treatment process, which means a lower usage of energy for aeration in the tanks and thus a lower energy consumption. Another improvement is the replacement of an old decanter centrifuge to a new more efficient one. In the same way old gas engines has been replaced with new ones which has increased the power production at the WTP.[10]

[5] https://en.biofos.dk/produktion/energi-og-ressourcer
[6] Some projects are implemented years ago and not all information is available in the desired level of detail. If data is not measured or for some other reason not available, a dash ('-') is presented in the summary table.
[7] Information from BIOFOS
[8] BIOFOS: Includes both reduces O&M costs and the saving from the energy reduction
[9] Information from BIOFOS
[10] https://www.waterworld.com/international/utilities/article/16201138/self-sufficient-wastewater-treatment-sharing-denmarks-sustainability-blueprint

The results from the mentioned initiatives are presented in the following table[11].

Technology/ project	Capital Invest-ment* (Mio. DKK)	O&M costs* (Thousand DKK/year)	Payback time (years)	Energy savings and increased pro-duction (MWh/year)	Emission reduction (ton CO_2e/year)**
Change to more effec-tive blowers and new membranes [12]	1.5	-	~4-5	300	43
Optimized online con-trol[13]	3	-	~2-3	700	100
Side-stream Anammox treatment process[14]	3	-	~5	50	7
Decanter centrifuge[15]	1.5	-330	~4	60	9
2+1 Gas en-gines[16]	12.7	-	~6	1900	272
Utilization of surplus heat	1.2	-	~5	2500	106
Total				**5510**	**537**

* Current prices
** Data provided by Aarhus Vand: Applied emission factor for electricity = 0,00014 tons CO_2/kWh, applied emission factor for heat = 0,0000425 tons CO_2/kWh

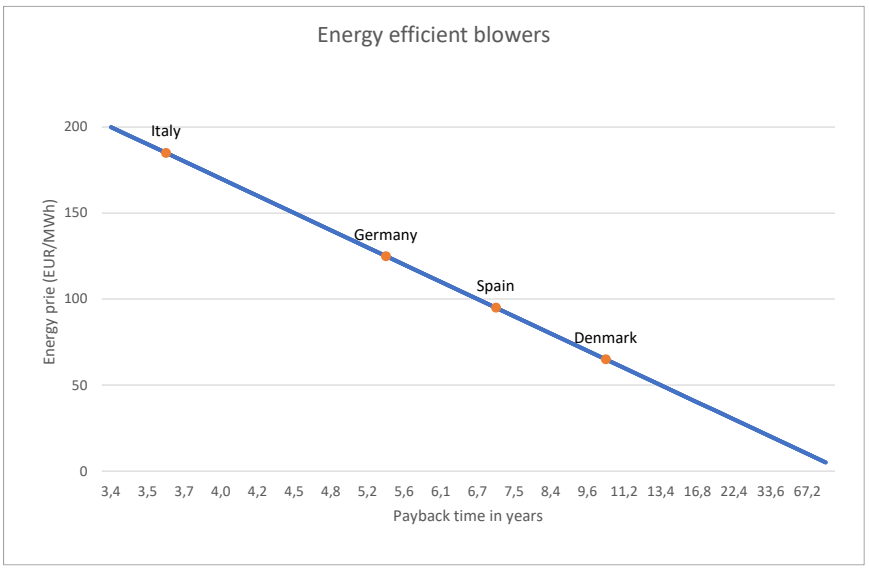
In regards to installing the 'Side-stream Anammox treatment process', it should be noted that at the time of implementation, this technology gave substantial tax benefits which made the technology more profitable and reduced the payback time.

[11] Some projects are implemented years ago and not all information is available in the desired level of detail. If data is not measured or for some other reason not available, a dash ('-') is presented in the summary table.
[12] DANVA, 'Vejen mod det energineutrale vandselskab', https://www.danva.dk/media/3259/lars_schroeder_aarhus_vand_oplaeg.pdf
[13] Investment of 400,000 EUR at the time according to WaterWorld, https://www.waterworld.com/international/utilities/article/16201138/self-sufficient-wastewater-treatment-sharing-denmarks-sustainability-blueprint
[14] Investment of 400,000 EUR at the time according to WaterWorld, https://www.waterworld.com/international/utilities/article/16201138/self-sufficient-wastewater-treatment-sharing-denmarks-sustainability-blueprint
[15] Informations from Aarhus Vand International. Applied exchange rate: 6.36 DKK/USD
[16] DANVA, 'Vejen mod det energineutrale vandselskab', https://www.danva.dk/media/3259/lars_schroeder_aarhus_vand_oplaeg.pdf

3 Opportunities in a European content

The report "Energy savings in the Danish Water sector" from 2016[17] shows that three specific energy saving technologies have a savings potential of 32,5 % of the total energy use. These three technologies are: optimization and control, bottom aeration and nitrogen removal using annamox.

The payback time of the projects leading to energy savings as described here, will to some degree depend on the price paid for energy in the form of electricity. As Denmark is one of the countries with the lowest energy price in EU, the payback time will be shorter in other countries with higher energy prices. This is due to the fact that higher energy prices inflate the value of energy savings[18]. This is illustrated below for the case of installing a more efficient blower at Marselisborg wastewater treatment plant.



It is illustrated that in Italy, where the price of electricity in 2019 was around 185 EUR/MWh, a similar initiative would have a simple payback time of around 3,5 years whereas in Denmark where the energy price of electricity is around 65 EUR/MWh the payback time is around 10 years.

Empirically, a potential for energy savings are often found at wastewater treatment plants – even at the plants that are newly built, as numerous equipment consumes energy in one form or another. However, the main question is: Is the payback time of investing in new and more energy efficient equipment acceptable – is the payback time sufficiently short? If not, it often still makes sense and is worthwhile to audit the plants – also newly built ones – in order to optimize the use of equipment in the light of the actual loads and energy use.

Installing new equipment will often lead to energy savings as newer equipment generally is more efficient and is able to meet more strict standards in terms of energy use. The use of equipment that is not due for replacement can often be

[17] The report in Danish published by the Danish Environmental Protection Agency is named "En Energibesparende Vandsektor".
[18] Source, energy prices: https://ec.europa.eu/energy/data-analysis/energy-prices-and-costs/energy-prices-eu-member-states-and-main-trading-partners_en

optimized through better monitoring and control strategies using SCADA (Supervisory control and data acquisition). Controlling the use of the equipment to the actual loads and desired results can thus lead to energy savings and it is often also possible to add equipment that leads to less energy consumption e.g. adding drives to pumps in order to follow and manage according to KPI's such as kWh/m^3. Generally speaking, it will make sense to audit and analyse wastewater treatment plants periodically in order to assess the potential energy savings. An energy audit is a first – but a crucial – step that enables utilities to prioritize initiatives and optimize the wastewater treatment and achieve energy and cost savings.

4 Detailed information on the cases

4.1 VCS Denmark – Ejby Mølle

Fig. Aerial photo of Ejby Mølle wastewater treatment plant provided by VCS Denmark

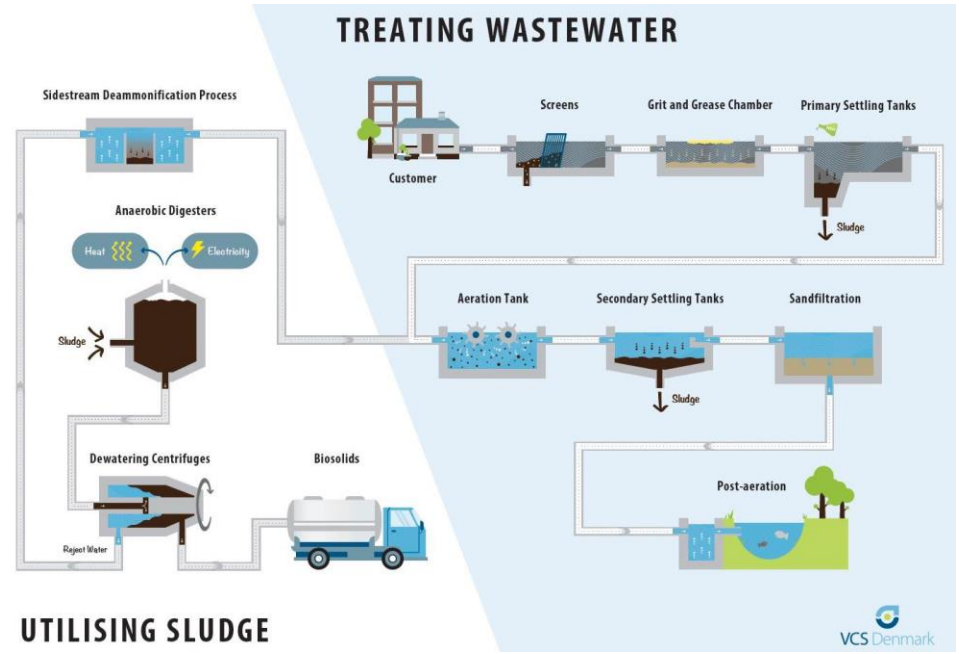


Fig. Illustration of wastewater treatment at Ejby Mølle WTP provided by VCS Denmark

- ✓ Location: Ejby Mølle wastewater treatment plant is located in Odense, which is the third largest city in Denmark
- ✓ Type of wastewater: Municipal
- ✓ Design concept: Biological treatment
- ✓ Capacity and load:
  - → Capacity: 385,000[19] - 410,000[20] person equivalents (PE)
  - → Total load (2019): 218,000 person equivalents (PE)[21]
  - → Treated wastewater (2020): 17.97 million m^3 [22]
- ✓ Electricity consumption and production (2019)[23]:
  - → Consumption: 7,964 MWh
  - → Production: 9,518 MWh
  - → Self-sufficiency ratio (energy – including heating) (2018)[24]: 180 %
- ✓ Energy efficiency (electricity):
  - → 10.9 Wh/NH4
  - → 1.71 Wh/BOD
- ✓ Average price of electricity (for processes): 0.48 DKK/kWh[25]

4.1.1 Selected initiatives

VCS Denmark and the staff at Ejby Mølle wastewater treatment plant persistently focus on reducing energy consumption[26]. In addition to monitoring and adjusting the processes in the highly energy consuming aeration tanks, older machinery has been replaced with new and more energy efficient machinery. Furthermore heat pumps replacing electrical heating have been installed and the inlet where grit is removed has been refurbished.

*4.1.1.1 **2018-2019**: Refurbishment of lifting pump station*

The lifting pump station at Ejby Mølle wastewater treatment plant annually pumps approximately 36,6 million m³ wastewater and was refurbished in 2018-2019. The refurbishment of the pump station included replacement of the older pumps from 1955 with new and more energy efficient pumps with a lower energy consumption. During the process of changing the pumps, the processes of distributing water were optimized as well in order to obtain a more efficient use of energy. This also involved replacing old drives with new variable frequency drives and equipping all pumps at the station with drives.

[19] https://stateofgreen.com/en/partners/vcs-denmark/solutions/wastewater-to-energy/
[20] https://www.thesourcemagazine.org/the-case-of-vcs-denmark-progress-beyond-net-energy-production/
[21] https://www.thesourcemagazine.org/the-case-of-vcs-denmark-progress-beyond-net-energy-production/
[22] Reference: VCS Denmark
[23] https://www.thesourcemagazine.org/the-case-of-vcs-denmark-progress-beyond-net-energy-production/
[24] https://www.vcsdenmark.com/services/advanced-wastewater-treatment/
[25] Reference: VCS Denmark
[26] https://www.vcsdenmark.com/services/advanced-wastewater-treatment/

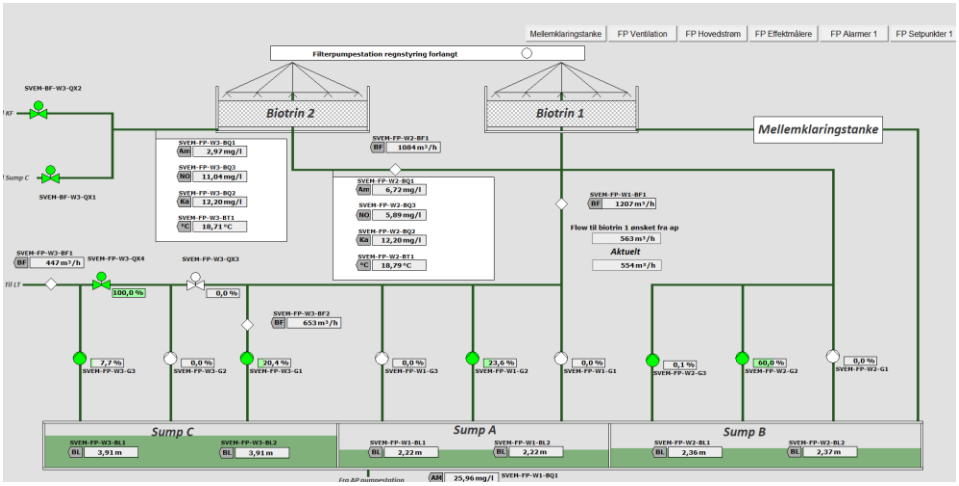


Fig. Scada-snapshot of filter station provided by VCS Denmark

Energy use, before (electricity): approx. 37 W/m³
Energy use, after (electricity): approx. 33 W/m³
Estimated savings per year (electricity): approx. 11,630 kWh

4.1.1.2 ***2020-2021**: Replacing two boilers with one new boiler*

Two 600 kW boilers from the 1980s, heating Ejby Mølle wastewater treatment plant were replaced with one new energy efficient 1000 kW boiler. As a result, energy production was increased due to less ventilation energy loss, and reduced energy loss from preheating the boilers. The expected annual energy savings (heating) are 235,000 kWh/year[27] and the expected total cost of heating for internal use is 12.13 DKK/GJ and excess heat from the boiler is sold to district heating at a price of approximately 85 DKK/GJ[28].

4.1.1.3 ***2020-2021**: Installation of heat pumps*

Heat pumps have not only been installed at Ejby Mølle wastewater treatment plant but also at a smaller wastewater treatment plant in Bogense.

At Ejby Mølle energy for district heating is extracted from the cleaned wastewater using four heat pumps with a combined capacity of 20 MW. The heat pumps primarily operate in autumn, winter and spring when the demand for district heating is increased. The expected annual production destined for the district heating system is approximately 71,500 MWh and the electricity use and transmission losses are 28,500 MWh[29].
The heat pump solution is owned and operated by the local distributor of district heating, Fjernvarme Fyn, and according to the available information on the project, the capital investment has been 99 million DKK and the operating costs 20 DKK/MWh. The accumulated net result during 20 years of operation is reportedly

[27] Article: The case of VCS Denmark – progress beyond net energy production
[28] Source: VCS Denmark
[29] Source: VCS Denmark

75 mio. DKK, by the assumption that the alternative cost of heating from biomass is 79 DKK/GJ[30].

At the smaller Bogense wastewater treatment plant, three air-to-air heat pumps for space heating have been installed by VCS Denmark. As a result, electricity consumption for space heating has decreased from approximately 50,000 kWh/year to 25,000 kWh/year. The capital cost of the heat pumps were around 46.000 DKK.

4.1.2 Economic data and emission reductions from initiatives

Based on the available information on the above mentioned energy saving initiatives, simple payback times and emission reductions have been calculated. The results are summarized in the following table[31].

Technology/ project	Capital Investment* (Mio. DKK)	O&M costs* (DKK/year) (Mio. DKK)	Payback time** (years)	Energy savings*** (MWh/year)	Emission Reduction**** (ton CO_2e /year)
Renovation of pump station	-	-	-	11.6	2.2
Replacement of old boilers	-	-	-	235	-
Heat pumps (Ejby Mølle)	99	1.5	10	709,071	6442
Heat pumps (Bogense)	0.04	-	3.5	25	4.7

* Current prices
** Calculated simple payback time
*** Different types of energy
**** Only emission reductions related to energy savings. Emission factors from virksomhedsguiden.dk or stated in the draft project approval

In the table, we find payback times between 3.5 and 10 years for the heat pump solutions. The energy savings from the different initiatives vary and the emission reductions from the energy savings vary accordingly.

4.1.3 General comments and learning points from VCS Denmark

Based on VCS Denmark's experience, wastewater plants, wastewater treatment equipment and -machines are more often than not oversized and consequently holds a capacity which exceeds the actual loads. When capacity exceeds the actual loads, the energy use is often higher than it could – and should – be. This means that there often are lots of "low hanging fruits" if plants and its equipment and machines are optimized by monitoring loads and energy use and adjusting accordingly.

An example is frequency control of pumps and adjusting the movement of wastewater with the least amount of energy use (electricity).
Another example is the case of mixers that are often designed to operate 24/7. However, because the mixers are oversized it is in some cases possible to reduce

[30] According to the draft project approval in which the life expectancy of the heat pump is assumed 25 years
[31] Some projects are implemented years ago and not all information is available in the desired level of detail. If data is not measured or for some other reason not available, a dash ('-') is presented in the summary table.

their hours of operation to 6 hours/day. Blowers are also often oversized in order to be able to produce enough air for the most extreme – but also most rare – situations. Smaller blowers with less capacity are more energy efficient, most of the time, but not necessarily designed for extreme situations.

As a result of continuous optimization of the wastewater treatment at Ejby Mølle wastewater treatment plant and VCS Denmark's other treatment plants, VCS Denmark has been able to make Ejby Mølle a net producer of energy and achieve a self-sufficiency percentage of 180.

4.2 Biofos – Avedøre

Fig. Aerial photo of Avedøre wastewater treatment plant provided by BIOFOS

- ✓ Location: Avedøre wastewater treatment plant is located outside Copenhagen, the capitol of Denmark
- ✓ Type of wastewater: Municipal
- ✓ Design concept: Biological treatment
- ✓ Capacity and load:
  - → Capacity: 400,000 person equivalents (PE)[32]
  - → Total load (2019): 333,261 person equivalents (PE)[33]
  - → Treated wastewater (2020): 22.9 million m^3 [34]
- ✓ Electricity consumption and production (2020)[35]:
  - → Consumption: 11,606 MWh electricity, 5887 MWh heating
  - → Production: 2286 MWh electricity, 5040 MWh heating
  - → Sales: 2286 MWh electricity, 2717 MWh heating, 3,070,000 Nm^3 biogas
  - → Self-sufficiency ratios: 19.7 % (electricity), 85.6% (heating). These ratios do not include the considerable amount of biogas produced and upgraded. The upgraded biogas – biomethane - is let into the natural gas grid system. Across Biofos the self-sufficiency energy ratio was 173% in 2020[36]

4.2.1 Selected initiatives

At the BIOFOS facility in Avedøre, a transformation from wastewater treatment plant to 'Water Resources Recovery Facility' is in the making[37]. The aim is to become 'Climate positive' in 2025 – less than 4 years from now – and from then on, continuously work towards further reductions in CO_2e-emissions.

The facility at Avedøre already produces and upgrades a considerable amount of biogas based on sludge from the wastewater. The upgraded biogas – biomethane - is let into the natural gas grid system.

[32] https://projekt-varga.dk/en/about-varga/
[33] https://www.danva.dk/media/7003/2020_vand-i-tal_web.pdf
[34] https://biofos.dk/media/a0tdwifp/biofos-milj-beretning-2020.pdf
[35] https://biofos.dk/media/a0tdwifp/biofos-milj-beretning-2020.pdf
[36] https://biofos.dk/media/jm4nqtnr/biofos-a-rsberetning_2020_06-07_web.pdf
[37] https://en.biofos.dk/produktion/energi-og-ressourcer

4.2.1.1 ***2015:*** *Bottom aeration*

At Avedøre wastewater treatment plant, the biological aeration tanks are now aerated with bottom aeration using Aerostrip diffusers instead of surface aeration. As a result, the energy efficiency has increased and thus provided energy savings around 40%[38].

4.2.1.2 ***2009-2011:*** *New inlet pump station*

Due to age and extensive wear and tear, the six pumps in the inlet station were replaced. The installation included new drives for the pumps, new screens as well as electrical wiring and SCADA (Supervisory Control And Data Acquisition). Five of the six pumps operate at a time with the last one as a spare.

4.2.2 Economic data and emission reductions from initiatives

Based on the available information on the above mentioned energy saving initiatives, simple payback times and emission reductions have been calculated. The results are summarized in the following table[39].

Technology/ Project	Capital Investment* (Mio. DKK)	O&M costs* (Mio. DKK/year)	Payback time** (years)	Energy Reduction (MWh/year)	Emission Reduction (ton CO_2e/year)
Bottom aeration[40]	49	3.7[41]	26.5	1,940	-
Inlet pump station[42]	29	-	-	-	-
* Current prices. ** Calculated simple payback time					

The payback time for bottom aeration is more than 25 years but it should be noted that at the time, this technology gave substantial tax benefits which made the technology more profitable and reduced the payback time. Another point of attention is that at the time of the investment, the energy prices were higher and thus the payback time shorter.

[38] Aquaconsult Anlagenbau GmbH, https://www.environmental-expert.com/articles/avedore-denmark-municipal-wwtp-case-study-706509
[39] Some projects are implemented years ago and not all information is available in the desired level of detail. If data is not measured or for some other reason not available, a dash ('-') is presented in the summary table.
[40] Information from BIOFOS
[41] BIOFOS: Includes both reduces O&M costs and the saving from the energy reduction
[42] Information from BIOFOS

4.3 Aarhus Vand – Marselisborg

Fig. Aerial view of Marselisborg wastewater treatment plant provided by Aarhus Vand

- ✓ Location: Marselisborg wastewater treatment plant is located in Aarhus, the second largest city in Denmark
- ✓ Type of wastewater: Municipal
- ✓ Design concept: Biological treatment
- ✓ Capacity and load:
  - → Capacity: 220,000 person equivalents (PE)[43]
  - → Total load (2019): 135,041person equivalents (PE)[44]
  - → Treated wastewater (2020): 10.9 million m^3 [45]
- ✓ Electricity consumption and production (2020)[46]:
  - → Consumption: 3.8 GWh/year
  - → Production: 4.7 GWh/year
- ✓ Heat consumption and production (2020):
  - → Consumption: 2,6 GWh/year
  - → Production: 4,8 GWh/year
- ✓ Energy Self-sufficiency (2020):
  - → Self-sufficiency ratio (electricity + heat): 151%

[43] DinGeo, https://www.dingeo.dk/renseanlaeg/158333
[44] The Danish Environmental Protection Agency, 'Punktkilder – 2019', https://www2.mst.dk/Udgiv/publikationer/2021/06/978-87-7038-327-1.pdf
[45] The Danish Environmental Protection Agency, 'Punktkilder – 2019', https://www2.mst.dk/Udgiv/publikationer/2021/06/978-87-7038-327-1.pdf
[46] Aarhus Vand International

Fig. Plant layout Marselisborg wastewater treatment plant provided by Aarhus Vand

4.3.1 Selected initiatives

Fig. Photo from Marselisborg wastewater treatment plant provided by Aarhus Vand

Aarhus Vand has introduced a number of initiatives to reduce the energy consumption at Marselisborg wastewater treatment plant. These include implementation of an advanced control system which provides energy reductions through online control and optimization of processes. It also includes replacement of old inefficient blowers with a highly efficient ABS HST compressor and installation of new membranes in the bottom aeration system, which increased the efficiency of the aeration and reduced the energy consumption as well as CO_2-emissions. The introduction of a side-stream Anammox sludge liquor treatment process means a lower usage of energy for aeration in the tanks and thus a lower energy consumption. Another improvement is the replacement of an old decanter centrifuge to a new and more efficient one. In the same way, old gas engines has been replaced with new ones and thereby increased the power production.[47]

4.3.1.1 ***2016:*** *Advanced control system*

The implementation of an advanced control system based on online sensors has been a key factor for optimising processes at Marselisborg and is also important for quality assurance. The system allows for online control of ammonium, nitrate and phosphor and frequency controllers at selected equipment are controlled

[47] https://www.waterworld.com/international/utilities/article/16201138/self-sufficient-wastewater-treatment-sharing-denmarks-sustainability-blueprint

online as well. The control system brought large energy savings and had a short payback time.[48]

4.3.1.2 ***2011:*** *Replacing three HV turbo blowers*

The replacement of three older HV turbo blowers with one highly efficient ABS HST compressor, reduced not only power consumption but also CO_2-emissions.[49] Furthermore, this change means less work in O&M as the old blowers needed weekly maintenance and a large yearly inspection whereas the new compressor only needs an annual change of filter and a smaller yearly service inspection. The change in costs from this is not quantified as the project was already profitable from the energy savings, so it is an added benefit.[50]

4.3.1.3 ***2014:*** *Introduction of a side-stream anammox*

The side-stream anammox treatment process uses red anammox bacteria to remove nitrogen from sludge liquor in an energy efficient way that requires less aeration compared to conventional methods and also do not require carbon. At Marselisborg WWTP implementation of the side-stream anammox plant has reduced the nitrogen load to the main process tanks with approximately 20%, resulting in a reduction of nitrogen in the outlet from the plant.[51]

The system needs different types of equipment and at Marselisborg wastewater treatment plant this includes; one blower, four pumps, two stirrers and some sensors. At Marselisborg they could reuse two old tanks which influences the investment costs and has to be taken into account when evaluating the profitability of the project.[52]

4.3.1.4 ***2016:*** *Installation of a new decanter centrifuge (2016)*

The replacement of the decanter centrifuge to a newer and more energy efficient one, meant a large cut in energy consumption and lowered the costs for O&M simultaneously. The decanter centrifuge dewaters waste sludge from digesters and the dry matter created from this process is used as fertilizer.[53] The new centrifuge is an Alfa-Laval G3 and the one it replaced was an Alfa-Laval 550.[54]

4.3.1.5 ***2010-12:*** *Installation of two new biogas engines*

Three biogas engines were replaced with two new (2 x 250 kW) and more efficient biogas engines (Power efficiency ~38%). This meant an increase in the amount of produced energy.

4.3.1.6 ***2013:*** *Surplus heat utilization for district heating system (2013)*

In 2013 Marselisborg WWTP started to sell its surplus heat to the district heating system. This meant an increase in net energy utilization.

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[48] https://www.waterworld.com/international/utilities/article/16201138/self-sufficient-wastewater-treatment-sharing-denmarks-sustainability-blueprint
[49] https://www.waterworld.com/international/utilities/article/16201138/self-sufficient-wastewater-treatment-sharing-denmarks-sustainability-blueprint
[50] Aarhus vand
[51] https://www.waterworld.com/international/utilities/article/16201138/self-sufficient-wastewater-treatment-sharing-denmarks-sustainability-blueprint
[52] Aarhus Vand
[53] https://www.waterworld.com/international/utilities/article/16201138/self-sufficient-wastewater-treatment-sharing-denmarks-sustainability-blueprint
[54] Information from Aarhus Vand

4.3.1.7 ***2015:*** *Installation of a new biogas engine and gas treatment (2015)*
Implementation of a new large biogas engine (355 kW) with a power efficiency of 40%. Gas treatment installed as well. As a result, increase in produced energy.

4.3.2 Economic data and emission reductions from initiatives

Based on the available information on the above mentioned energy saving initiatives, simple payback times and emission reductions have been calculated. The results are summarized in the following table[55].

Technology/ project	Capital Investment* (Mio. DKK)	O&M costs* (Thousand DKK/year)	Payback time (years)	Energy savings and increased production (MWh/year)	Emission reduction (ton CO_2e/year)**
Change to more effective blowers and new membranes [56]	1.5	-	~4-5	300	43
Optimized online control[57]	3	-	~2-3	700	100
Side-stream Anammox treatment process[58]	3	-	~5	50	7
Decanter centrifuge[59]	1.5	-330	~4	60	9
2+1 Gas engines[60]	12.7	-	~6	1900	272
Utilization of surplus heat	1.2	-	~5	2500	106
Total				**5510**	**537**

* Current prices
** Data provided by Aarhus Vand: Applied emission factor for electricity = 0,00014 tons CO_2/kWh, applied emission factor for heat = 0,0000425 tons CO_2/kWh

In regards to installing the 'side-stream anammox treatment process', it should be noted that at the time, this technology gave substantial tax benefits which made the technology more profitable and reduced the payback time.

[55] Some projects are implemented years ago and not all information is available in the desired level of detail. If data is not measured or for some other reason not available, a dash ('-') is presented in the summary table.
[56] DANVA, 'Vejen mod det energineutrale vandselskab', https://www.danva.dk/media/3259/lars_schroeder_aarhus_vand_oplaeg.pdf
[57] Investment of 400,000 EUR at the time according to WaterWorld, https://www.waterworld.com/international/utilities/article/16201138/self-sufficient-wastewater-treatment-sharing-denmarks-sustainability-blueprint
[58] Investment of 400,000 EUR at the time according to WaterWorld, https://www.waterworld.com/international/utilities/article/16201138/self-sufficient-wastewater-treatment-sharing-denmarks-sustainability-blueprint
[59] Informations from Aarhus Vand International. Applied exchange rate: 6.36 DKK/USD
[60] DANVA, 'Vejen mod det energineutrale vandselskab', https://www.danva.dk/media/3259/lars_schroeder_aarhus_vand_oplaeg.pdf