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Energy neutrality of the European wastewater sector: Inventory of typology and definitions of energy use and energy production

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Abstract

The recast Urban Wastewater Treatment Directive (UWWTD) asks the wastewater sector in each Member State (MS) to achieve energy neutrality by 2045, hence wastewater operators larger than 10,000 Population Equivalent (PE) should produce 100% of their energy consumption by renewable energy, but up to 35% of non-fossil energy can be bought from the grid if, according to the results of the audits, the national target of 100% neutrality cannot be achieved. The scope of this document is to establish a typology and definitions of energy uses and energy production opportunities at treatment plant level (including on- / off-site uses). The document also proposes the methodology for the calculation of energy neutrality.

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Executive summary

Policy context

The recast UWWTD asks the urban wastewater sector in each Member State (MS) to achieve energy neutrality by 2045, hence wastewater operators larger than 10,000 Population Equivalent (PE) should produce 100% of their energy consumption by renewable energy, but up to 35% of non-fossil energy can be bought from the grid if, according to the results of the audits, the national target of 100% neutrality cannot be achieved. The scope of this document is to establish a typology and definitions of energy uses and energy production opportunities at treatment plant level (including on- / off-site uses) and how to consider them in the calculation of energy neutrality. The energy neutrality target also aims at increasing the independence of the European energy sector, fostering renewable energy technologies and their connection with other energy policies, like the Renewable Energy Directive and the Energy Efficiency Directive. Meanwhile, competitiveness of the European industry is also fostered, by promoting the use of net-zero and EU made technologies, as also supported by the Net-Zero Industry Act, and wastewater reuse, in line with the Water Reuse regulation and the Water Resilience Strategy. This study is conceived to support the Implementing Act of the Directive.

Key conclusions

Main findings

Related and future Joint Research Centre work

Quick guide

1. Introduction

The recast Urban Wastewater Treatment Directive (UWWTD) EU/3019/2024 stipulates:

1. Member States shall ensure that energy audits, as defined in Article 2, point (32), of Directive (EU) 2023/1791, of urban wastewater treatment plants and collecting systems in operation are carried out every four years. Those audits shall include an identification of the potential for cost-effective measures to reduce the use of energy and enhance the use and production of renewable energy, with a particular focus on identifying and utilising the potential for biogas production or the recovery and use of waste heat either on-site or via a district energy system, while reducing GHG emissions. The first energy audits shall be carried out:

(a) by 31 December 2028 for urban wastewater treatment plants treating a load of 100 000 p.e.[1] and above and the collecting systems connected to them;

(b) by 31 December 2032 for urban wastewater treatment plants treating a load of 10 000 p.e. and above but below 100 000 p.e. and the collecting systems connected to them.

2. Member States shall ensure that, at national level, the total annual energy from renewable sources, as defined in Article 2(1) of Directive (EU) 2018/2001, generated on-site or off-site by or on behalf of the owners or the operators of urban wastewater treatment plants treating a load of 10 000 p.e. and above, and irrespective of whether that energy is used on-site or off-site by the owners or operators of those plants, is equivalent to at least:

(a) 20 % of the total annual energy used by such plants by 31 December 2030;

(b) 40 % of the total annual energy used by such plants by 31 December 2035;

(c) 70 % of the total annual energy used by such plants by 31 December 2040;

(d) 100 % of the total annual energy used by such plants by 31 December 2045.

Renewable energy generated by or on behalf of the owners or operators of the urban wastewater treatment plant shall not comprise purchased renewable energy.

3. By way of derogation from paragraph 2, if a Member State does not reach the objective referred to in paragraph 2, point (d), despite having implemented all energy efficiency measures and all measures necessary to enhance the production of renewable energy, in particular those identified in the energy audits referred to in paragraph 1, Member States may exceptionally allow the purchase of energy from non-fossil fuel sources. Those purchases shall be limited to a maximum of 35 % of non-fossil fuel energy in relation to the objective referred to in paragraph 2, point (d). Electricity

[1] 1 population equivalent' or '1 p.e.' means the organic biodegradable load per day, having a five-day biochemical oxygen demand (BOD_5) of 60 g of oxygen per day.

purchased by Power Purchase Agreements should count in the energy neutrality balance, so should not be part of the 35% derogation.

4. By way of derogation from paragraph 2, if a Member State does not reach the objective referred to in paragraph 2, point (c), despite having implemented all energy efficiency measures and all measures to enhance the production of renewable energy, in particular those identified in the energy audits referred to in paragraph 1, Member States may exceptionally allow the purchase of energy from non-fossil fuel sources. Those purchases shall be limited to a maximum of 5 percentage points of the objective referred to in paragraph 2, point (c). That derogation shall be granted only to Member States that can demonstrate by 31 December 2040 that 35 % of external non-fossil fuel energy as referred to in paragraph 3 will need to be purchased to reach the objective referred to in paragraph 2, point (d), taking into account all energy efficiency measures and all measures necessary to enhance the production of renewable energy, in particular those identified in the energy audits referred to in paragraph 1.

5. The Commission may adopt an implementing act for establishing the methods to assess whether the objectives in paragraph 2 have been met. That implementing act shall be adopted in accordance with the examination procedure referred to in Article 28(2).

This report reviews the typology and definitions of energy uses and energy production opportunities at treatment plant level (including on- off-site uses and production as established in Article 11 and the corresponding recital).

To this end, the JRC has coordinated an expert group to discuss how energy neutrality should be calculated, and to redact an inventory of typologies and definitions of energy sinks and energy production opportunities.

2. The energy balance of a WWTP

The objective of this chapter is to provide an inventory of the types of energy use (section 2.2) and opportunities for energy production (section 2.3) in wastewater treatment.

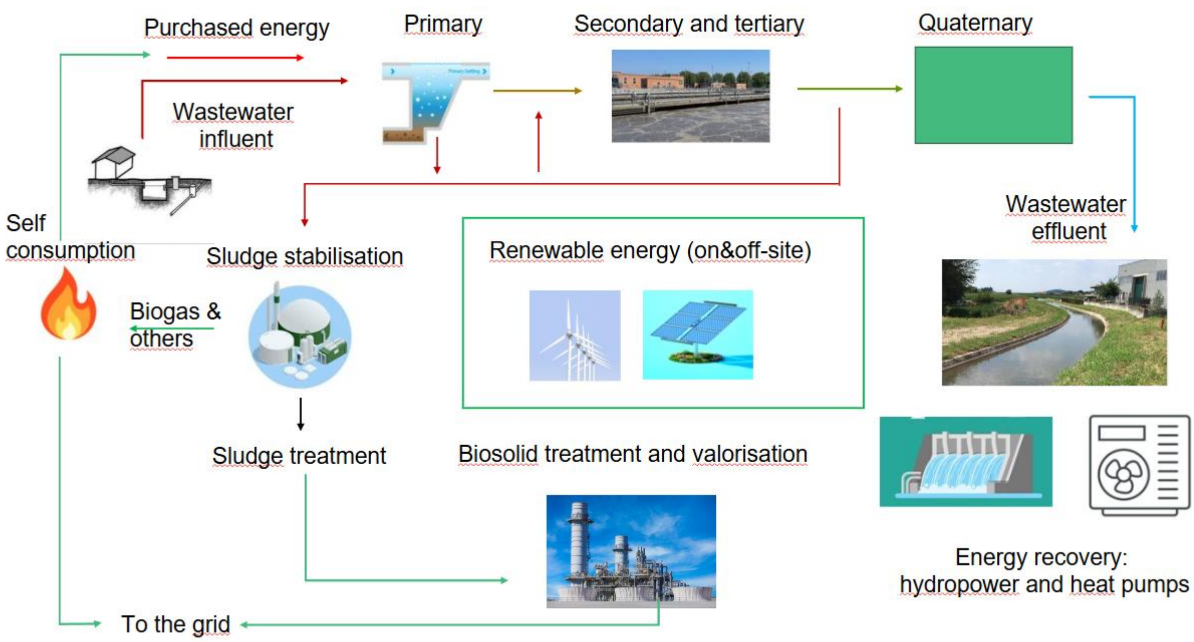
2.1. Overview

The calculation of energy neutrality should demonstrate which percentage of the energy used in wastewater treatment plants (WWTPs) is covered by the energy generated by the WWTP owners or operators. To this end, the calculation should be limited to the energy use within the plant premises, excluding the energy used for pumping sewage from the collection network to the inlet of the plant and from the plant to the discharge point.

Figure 1 shows a scheme of the components of a WWTP where energy is used. Wastewater treatment generally involves a series of physical, chemical, and biological processes to remove contaminants and pollutants from wastewater before it is discharged or reused. These processes are typically categorized into preliminary, primary, secondary, tertiary and quaternary processes, along with sludge treatment and nutrient recovery.

0. Preliminary Treatment focuses on removing large debris and grit that could damage equipment in later stages.
1. Primary Treatment involves physical processes to separate settleable solids and floatable materials.
2. Secondary Treatment utilizes biological processes to remove dissolved and suspended organic matter.
3. Tertiary Treatment involves advanced treatment processes to remove specific pollutants (nitrogen, phosphorous) or pathogens that may remain after secondary treatment.
4. Quaternary Treatment means treatment of urban wastewater by a process which reduces a broad spectrum of micropollutants in urban wastewater.
5. Sludge Treatment to reduce volume (water content) of the sludge.
6. Nutrient recovery, mainly ammonia and phosphorous.

Figure 1. Simplified diagram of the main stages of a wastewater treatment plant, including digestion of sludge to produce biogas.



2.2. Energy use in a WWTP

As a rule of thumb, based on a survey on 98 WWTPs across Europe from the ENERWATER project, we can break down the energy used in a WWTP roughly as:

Pumping: 12%

Primary Settling: 1.5%

Secondary treatment (whole): 52%

Tertiary treatment:12%

Sludge thickening and dewatering: 23%

When quaternary treatment is added, total energy consumption can increase by approx. 20%.

In the next sections, we provide more details on the use of energy in the various sections of the wastewater treatment process, and **Error! Reference source not found.** in Appendix 1 shows the range of various energy consumptions of different processes, from Longo et al. (2016), based on a collection of several WWTPs across Europe.

Throughout this report, we refer to the direct use of energy as well as the energy embedded in the chemicals and other inputs required by the processes, insofar as relevant. The implications of a possible consideration of this embedded energy when addressing energy neutrality are discussed in Section 4.1.4.

2.2.1. Wastewater Pumping/lifting

Energy used for pumping within the plant should be counted, excluding the energy used for pumping sewage from the collection network to the inlet of the plant and from the plant to the discharge point.

Ideal pumping energy requirements are 0.0027 kWh per m^3 of water and 1 m of hydraulic head difference. Taking into account the type of pump used the actual value can vary, although not significantly, as pumping energy efficiency is probably close to 55% for less efficient pumps up to 80% for the most efficient pumps (lumping together the electrical and mechanical losses). Note that the energy efficiency is also linked to the nature of the fluid to be pumped.

Although some indications can be found, as the pumping head is linked to the topography of the WWTP, it is difficult to assign a specific energy use per PE.

Specific energy use (kWh/(PE·y))	Specific energy use (kWh/m^3)	Source
0.23-0.33	0.0032-0.0045	(Tchobanoglous et al., 2014)
	0.0045-0.0054 (kWh/m^3·m head) for spiral pump or centrifugal pump (single impeller) both raw sewage	(Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA), 2015)
	0.0036-0.0042 (kWh/m^3·mhead) for multiport centrifugal pumps, return activated sludge (RAS), internal flows, etc.	(Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA), 2015)
0.35	0.0048	Project Enerwater database (98 WWTPs) This value is for the entire pretreatment + WW pumping along the WWTP (Longo et al., 2019)
0.37-0.77		Own data (mostly small WWTPs)

2.2.2. Primary treatments

2.2.2.1. Screening

Specific energy use (kWh/(PE·y))	Specific energy use (kWh/m^3)	Source
0.02-0.04	0.0003-0.0005	(Tchobanoglous et al., 2014)
0.05-0.1 (for rakes operation)	_	(Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA), 2015)
0.3-0.8		Own data (mostly small WWTPs)
0.1-0.3		Baumann et al., 2024

2.2.2.2. Degritting and degreasing

Specific energy use (kWh/(PE·y))	Specific energy use (kWh/m^3)	Source
0.22 - 0.95 (aerated grit removal)	0.003-0.013	(Tchobanoglous et al., 2014)
0.2-0.4		Own data (mostly small WWTPs)
0.5-1.9		Baumann et al., 2024

2.2.2.3. Primary settling

Specific energy use (kWh/(PE·y))	Specific energy use (kWh/m^3)	Source
0.30 (primary settler operation)	0.0039 28 kWh/kgTSS removed	Project Enerwater database (98 WWTPs) (Longo et al., 2019)
0.1 – 0.4		Baumann et al., 2024

2.2.3. Secondary and tertiary treatments

Specific energy use (kWh/(PE·y))	Specific energy use (kWh/m^3)	Source
4.5 – 6.9 trickling filter 10.2 – activated sludge 16.8 – activated sludge + N/DN 36-73 – membrane bioreactor	0.06-0.09 – trickling filters 0.14 – activated sludge with nitrification/denitrification 0.5-1.0 membrane bioreactor	(Tchobanoglous et al., 2014)
16 (aeration consumption, median of 111 WWTP survey)		(Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA), 2015)
10.7 - 14,5 (calculated 120 gCOD/(PE·y))) and SSOTE of 20%	Standard Aeration Efficiency 3.3-4.5 kg/kWh	(Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA), 2015)
29.0 based on design PE 54.7 for an MBR		Own data (mostly small WWTPs)
11.2-18.1		Baumann et al., 2024

2.2.4. Mixing reactors

Specific energy use (kWh/(PE·y))	Specific energy use (kWh/m^3)	Source
5-9		Own data (mostly small WWTPs), anoxic tanks, ENERWATER
1.9-5.4		Anaerobic digesters, Baumann et al. (2024)
	0.005-0.008	Anaerobic digesters

2.2.5. Recirculation

This depends so much on the process. An indication would be 0.8 – 2.3 kWh/PE/y, or 1.3 kWh/PE/y.

2.2.6. Return sludge pumping

Specific energy use (kWh/(PE·y))	Specific energy use (kWh/m^3 of influent)	Source
0.59 – 0.95	0.008-0.013	(Tchobanoglous et al., 2014)
3-10		Own data (mostly small WWTPs)
1.7-4.4		Baumann et al., 2024

2.2.7. Clarification or Secondary Settling

Specific energy use (kWh/(PE·y))	Specific energy use (kWh/m^3 of influent)	Source
0.2 – 0.3	0.003-0.004	(Tchobanoglous et al., 2014)
0.8-1.8		Own data (mostly small WWTPs)
0.4-1.5		Baumann et al., 2024

2.2.8. Filtration

Specific energy use (kWh/(PE·y))	Specific energy use (kWh/m^3 of influent)	Source
2.1 – 5.8 as general range	0.03-0.08	(Tchobanoglous et al., 2014)
4.5-5.0 (sand filtration only)		Baumann et al., 2024,
	0.02 – 0.025 (disc filter)	Baumann et al. 2024

2.2.9. Quaternary

2.2.9.1. Activated carbon

The energy consumption for the quaternary treatment can be differentiated between the energy consumption of the plant and the primary energy including the production of the activated carbon.

Total energy consumption main stage and post treatment for quaternary treatment:

	Specific energy use (kWh/(PE·y))	Specific energy use (kWh/m^3 treated)	Source
Powder active carbon	2.0 – 9.0	0.02 – 0.1	Joller and Hug, 2024
Granular active carbon	2.0 – 5.0	0.025 – 0.07	Joller and Hug, 2024

Primary energy consumption incl. production and transport

	Primary energy consumption (kWh/(PE·y))	Primary energy consumption (kWh/m^3 treated)	Source
Powder active carbon	22.0 – 80.0	0.25 – 0.8	Joller and Hug, 2024
Granular active carbon	30.0 – 40.0	0.4 – 0.6	Joller and Hug, 2024

2 – 2.5 kWh/PE/y (excluding AC generation).

AC generation generally consumes 4-13 kWh/kg heat and 0.1-0.3 kWh/kg of electricity (Hoyer et al., 2022).

Primary energy consumption for fresh and reactivated active carbon (DWA-M 285-2, 2021)

		Primary energy consumption (GJ / Mg AC)
Hard coal	Fresh AC	109 - 124
	Reactivated AC	17 - 29
Brown coal	Fresh Ac	152 – 184
	Reactivated AC	20 – 37
Coconut Shell	Fresh AC	28 – 51
	Reactivated	9 - 14

Active carbon consumption of quaternary treatment (Joller and Hug, 2024)

	Specific active carbon use (kg/(PE·y))	Specific active carbon use (mg/l)	Source
PAC and GAC	0.5 – 2.0	5.0 – 20.0	(Joller and Hug, 2024)

2.2.9.2. Ozone generation

15 – 23 kWh/PE/y for on-site ozone generation.

2.2.10. Disinfection and other advanced treatment

	Specific energy use (kWh/(PE·y))	Specific energy use (kWh/m^3 of influent)	Source
UV disinfection	0.7 – 3.7	0.01-0.05	(Tchobanoglous et al., 2014)
UV disinfection	1.5 This value is for the entire pretreatment + WW pumping along the WWTP	0.02	Project Enerwater database (98 WWTPs) (Longo et al., 2019)
UV disinfection		0.03 – 0.06	Baumann et al. 2024
Microfiltration/Ultrafiltration		0.2 – 0.3	Metcalf and Eddy (2014)
Reverse osmosis		0.46 – 0.6	Metcalf and Eddy (2014)
Chlorination	This requires very little energy, it is mostly the production of the chemical.		
Electrodialysis		1.1 – 2.2	Metcalf and Eddy (2014)

2.2.11. Sludge treatment

2.2.11.1. Sludge pumping/transport

Within the WWTP (very variable).

2.2.11.2. Thickening

Specific energy use (kWh/(PE·y))	Specific energy use	Source
0.02-0.12 – gravity thickening	0.0003-0.0016 (kWh/m^3 of influent) – gravity thickening	(Tchobanoglous et al., 2014)
<0.9 - gravity thickening/rotary drum 2.9 - 4.1 - centrifuge with flocculant 5.3 – 6.4 – centrifuge without flocculant 2.9 - 4.1 – dissolved air flotation All calculated as PE sludge production of 80 gTSS/PE/d	<0.03 (kWh/kg TSS of sludge) – gravity thickening/rotary drum 0.10-0.14 (kWh/kg TSS of sludge) – centrifuge with flocculant 0.18-0.22 (kWh/kg TSS of sludge) – centrifuge without flocculant 0.10-0.14 (kWh/kg TSS of sludge) – dissolved air flotation	(Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA), 2015)
0.4-0.6 – gravity thickening		Own data (mostly small WWTPs)

2.2.11.3. Hydrolysis

Hydrolysis improves dewaterability and degradability. It depends on dry matter of the sludge, sludge composition (Waste Activated Sludge-WAS-, or primary sludge -PS-), temperature difference and heat losses/potential for heat exchange. Energy consumption could be estimated at 0.29 kWh/kg Dry sludge (for WAS) (Barbel, 2020).

2.2.11.4. Sludge dewatering

Specific energy use (kWh/(PE·y))	Specific energy use	Source
0.4 - 1.0 – gravity thickening	0.005-0.013 (kWh/m^3 of influent) – centrifuge	(Tchobanoglous et al., 2014)
0.8 - 1.7 – centrifuge 0.4 - 0.9 – band filter 0.6 - 1.3 – filter press Screw technology All calculated as PE sludge production of 80 gTSS/PE/d, and for digested sludge (50% VSS removal in AD, 70% VSS/TSS entering AD)	0.04-0.09 (kWh/kg TSS of sludge) – centrifuge 0.02-0.05 (kWh/kg TSS of sludge) – band filter 0.005-0.02 kWh/kg TSS 0.03-0.07 (kWh/kg TSS of sludge) – filter press	(Deutsche Vereinigung für Wasserwirtschaft, Abwasser und Abfall e. V. (DWA), 2015)
1.4-2.3 - centrifuge		Own data (mostly small WWTPs)

2.2.11.5. Odor treatment

The energy in AC filtration due to the compression of the odorous emission is 5.3 ± 0.6 kWh $(m^3/h)^{-1}$air treated. Biofilters and chemical scrubbers present comparable annual energy consumptions (4.2 ± 0.8 kWh $(m^3/h)^{-1}$air treated) followed by biotrickling filters (1.9 ± 0.3 kWh $(m^3/h)^{-1}$air treated). These annual energy requirements were estimated in the best and worst case scenarios and were lower than those in incinerators or AC filters. Biofilter operation at pressure drops of 2 cm H2O would result in energy consumptions of 0.19 kWh $(m^3/h)^{-1}$ air treated (Estrada et al., 2011). Based on data of an operator, use of chemicals might include NaOH (0.02-0.03 g/Nm3 of treated air), sulfuric acid (0.02 g/Nm3 of treated air) and hypochlorite (0.03-0.09 g/Nm3 of treated air).

2.2.11.6. Sludge drying

Minimum thermodynamic requirement for sludge drying can be calculated based on sensible and latent heat that is necessary to evaporate water, which is approximately 0.63 kWh/kg. In practice, heat demand (depending on technology) range from 0.82 to 1.1 kWh/kg evaporated water. Total sludge drying energy demand can on average be estimated at approximately 2.5 kWh/kg dry sludge

(Capodaglio and Olsson, G., 2020), but can also reach 5 kWh/kg dry matter of dry sludge, according to same case studies.

2.2.11.7. Sludge transport off-site

It is site specific and generally quite marginal to the total energy balance, see section 4.2.

2.2.12. Anaerobic digestion heating

Anaerobic digestion (AD) of wastewater sludge generally requires heat to maintain optimal operating temperatures for microbial activity, typically within the mesophilic (30-40°C) or thermophilic (50-60°C) ranges. While AD is a slightly exothermic process, external heating is required to reach and maintain the desired operating temperature. The process heat demand is in the range of 5-15% of the energy available in the biogas produced (Scholwin and Nelles, 2013). For a typical mesophilic biogas plant 0.62 kWh are required per m3 of reactor volume (Garkoti et al., 2024). The heat demand is influenced by several factors, including the feedstock temperature, temperature range, digester design, and heat losses. Heat losses are dependent on area of wall, base and top surface, loss from heat exchanger (typically 5%) and the heat transfer coefficient depends on wall material, insulation, ambient temperature (Garkoti et al., 2024). 1.7 – 4.5 kWh/PE/y is a common range.

2.2.13. Biogas purification

Energy demand for biogas purification is strongly dependent on contaminant present in the gas and its concentration (mainly hydrogen sulphide, siloxanes, water) and the purification process chosen. From an energy perspective biogas purification is neglectable, but losses might occur.

2.2.14. Biogas upgrading

While different upgrading technologies show a large range of energy use between 0.1 and 0.8 kWh/m^3 biogas, water scrubbing and physical scrubbing are cheaper, with widespread deployment, and have a more consistent energy use between 0.2 and 0.5 kWh/m^3 biogas (Feng and Rosa, 2024). Chemical treatments may entail energy consumption embedded in chemicals. 3.6%-10.8% of the total biomethane producible from waste biomass is used in the biogas upgrading process

2.2.15. Buildings

This includes Heating, Cooling, Electricity. All ancillary services including operation of the plant's buildings also for laboratories, storage, management and administration purposes should be factored in.

2.2.16. General and maintenance

This includes cleaning, washing, de-fouling and other minor processes.

2.3. Opportunities for energy generation

2.3.1. From sludge

2.3.1.1. Biogas

The ratio of national energy production (in terms of m^3/year of biogas) to the population equivalent, at member state level, ranges between 1.1 m^3/PE (Italy and Portugal) to 12 m^3/PE (Sweden), with a median value of 3.5 m^3/PE per year (from Eurobserver, Eurostat and WWTP EEA database). The biogas production (in terms of kWh of heat content) per m^3 of influent wastewater ranges between 0.18 and 1.67 kWh/m^3, in line with literature, with a median EU value of 0.59 kWh/m^3 (Quaranta et al., 2025, in progress).

By considering energy valorization by Combined Heat and Power (CHP), it is possible to assume biogas losses of 10% (pessimistic value), an electric efficiency of 35-42% (the smaller for smaller CHP systems) and a thermal efficiency of up to 90% on the heat that is effectively recovered (see also section 4.2).

Co-digestion would also count if implemented in the digestor owned by the WWTP operator. Co-digestion will increase biogas production, but additional energy consumption to treat the co-digested substrate should be taken into account, as well as the presence of pollutant substances in the other substrates.

2.3.1.2. Biomethane

Biomethane can be used as a fuel for vehicles, heating, engines, and gas turbines, and can also be injected into the natural gas grid. A lower heating value of 13.9 kWh/kg can be considered. It is important to consider leaks in biomethane supply chains in future planning, as current measurements show leakage rates of ~6% (Feng and Rosa, 2024), while for the EU the leakages could be set at around 2.5% as for the Danish case (Fredenslund et al., 2023).

2.3.1.3. Incineration

The heat content of the sludge should be computed by the operator. For a preliminary estimate, it can be assumed 3.3 kWh/kg of dry matter for dried digested sludge at 100%, to which energy associated to sensible heat and latent heat of water needs to be deduced, depending on water content. Energy for treating this sludge should be computed once, and not double counted in the energy consumption terms. In case of co-incineration, only the energy from the sludge should be computed, based on calorific value and quantity used.

2.3.1.4. Pyrolysis

The pyrolysis process converts the sludge into biochar, pyrolysis oil, and gas, significantly reducing the sludge's volume and weight while achieving high levels of hygienization and contaminant destruction and minimizing GHG emissions from digestate storage and handling. Compared to AD, pyrolysis offers faster processing (less than an hour). Biochar also retains phosphorus and can improve soil health, contributing to carbon sequestration, but, more important, it can reduce the content of micropollutants (PFAS and heavy metals). However, the technology is more complex, has higher electricity demands (including sludge drying), and requires robust emission control systems (10 % higher compared to a treatment plant with AD at the same capacity). Energy consumption estimated at 7.1 kWh/PE year (Roslagsvatten and Miljö, 2023) with syngas energy content of approx. 1-3 kWh/Nm3. One example is discussed in Annex 2.

2.3.2. From effluents

2.3.2.1. Heat pumps

Heat recovery by heat pumps on the effluent of the WWTP is also a relevant strategy. The temperature of wastewater is generally in the range between 10°C and 23°C depending on the latitude and altitude. This temperature can be exploited for heat recovery, or cooling generation, by heat pumps and be used for local purposes (drying, heating) or for district heating (or cooling) if distances are small (generally, less than 3 km) and if the flow is higher than a certain amount (15 l/s). In general, up to 20% of the effluent discharge can be exploited, with a temperature drop of up to to 5°C.

2.3.2.2. Hydropower

Hydropower systems can exploit the available head downstream of the wastewater treatment plants. The hydropower potential is approximately 100 GWh/y and could be very relevant in specific conditions where there is a certain head at the effluent point (Llácer-Iglesias et al., 2021; Quaranta et al., 2022).

2.3.3. Other renewables using available spaces at WWTPs

2.3.3.1. Photovoltaics

Photovoltaic electricity generation depends on the exploited area A (m2) and on the electricity generation for unit area Ea (kWh/m2), that depends on the solar radiation (affected by meteorological conditions), efficiency of the panel, panel's inclination angle and spacing. From Bódis et al. (2019) it is possible to calculate the average value of Ea for each Member State, and the average value is 0.23 kWh/m²/day for the EU on roofs.

The exploitable areas for PV generation in WWTPs mainly include:

- Buildings' roofs
- sedimentation tanks
- off-site installations

Covering building's roofs seems to be the most feasible approach. The anaerobic digester's area has already been exploited with solar panels for heating purposes (Panchenko et al., 2023), while the installation of photovoltaics would be very risky, due to the explosive ambient. Panchenko et al., (2023) described that solar thermal collectors around digesters reduce the thermal losses of the digester and have a positive effect on the thermal balance of the digester. Covering sedimentation tanks requires high investments and installation costs. According to Strazzabosco et al. (2019), solar PV adoption is convenient in WWTPs above 10,000 PE.

2.3.3.2. Wind

Wind farms are not so common on-site. However, two examples of large installations are worth mentioning (see Annex 2).

2.3.4. Emerging technologies and future possibilities

2.3.4.1. (Microbial) fuel cells

Microbial fuel cells (MFCs) can be used to treat wastewater and generate electricity at the same time, with more of a focus on the former. MFCs can generate electricity from various organic materials like industrial wastewaters, food waste, and municipal wastewater. Recent research has used sewage sludge in MFCs. However, MFCs suffer from low electricity generation, which limits their development and industrial application. Nonetheless, their reduced sludge production compared to conventional sludge treatment processes can address concerns about treatment and disposal costs. MFCs are not (yet) very efficient at producing electricity, but rather their advantage is for wastewater treatment. MFCs are still in the early stages of development, with most applications at the pilot scale (source: CETO expert).

2.3.4.2. Ammonia

The production of mineral nitrogen fertilizers requires a lot of energy because hydrogen is needed to bind nitrogen from the air in the most common process. In the so-called Haber-Bosch process, ammonia is formed from nitrogen gas and hydrogen. The hydrogen gas is produced from natural gas, or from coal or oil in combination with water. To produce ammonia, about 9.5 kWh/kg N is required when using natural gas as the energy source (Hoxha and Christensen, 2019). With a global production of approximately 150 million tons of ammonia nitrogen annually, the fertilizer industry accounts for about 28% of all natural gas consumption in the world, and therefore also for a large share of greenhouse gas emissions, especially since the process releases not only carbon dioxide but also nitrous oxide.

Nitrogen removal accounts for a large part of the costs for wastewater treatment in those WWTPs that are subject to nitrogen removal requirements. This is because nitrogen removal leads to increased aeration needs, more water pumping (nitrate return for pre-denitrification), and sometimes the addition of an external carbon source as a complement to pre-denitrification in WWTPs with strict discharge requirements. The addition of fossil-based external carbon sources and the emission of nitrous oxide in connection with nitrogen removal means that this process can account for the majority of the climate impact of a WWTP Energy demand for nitrification/denitrification can be estimated at 4 kWh/kg N reduced. (Malovanyy et al., 2022).

For established nitrogen recovery technologies with a TLR higher than 8 the energy demand ranges from 1-6.6 kWhel per kg N (traditional stripping, membrane contactors, struvite precipitation) and is substantially lower than the energy demand for fixation of nitrogen and nitrification/denitrification during the wastewater treatment process. It has to be noted that the recovered nitrogen from those processes is not comparable with a commercial mineral fertilizer but could substitute raw material in the production of such fertilizers.

Ammonia is, besides being an important component in mineral fertilizers, explored as a carbon-free energy carrier. Though the energy density (5.17 kWh/kg) is lower than gasoline (ca. 12.5 kWh/kg), the volumetric energy density is higher than for hydrogen. Also, ammonia is easier to store and liquify compared to hydrogen and transport and storage infrastructure exists globally due to its use as fertilizer. The energy demand to produce ammonia is 7.8 kWh per kg via the Haber Bosch process mentioned above.

2.3.4.3. Material recovery

Although this is not the scope of this report, material recovery can be implemented, and also be quite energy intensive. However, the energy to recover materials should not be counted in the energy balance calculation, as long as the material is effectively used by other industries, where the energy consumption should be considered, eventually. The main substances that could be recovered are phosphorous, bioplastic, cellulose (In the last decade, a few sites have adopted this technology, mainly in Europe and North America, Espíndola et al., 2021) and Extracellular polymeric substances (EPS).

3. Case studies

[under development]

In order to take into account the specificities of each urban wastewater treatment plant, optimise the investments needed and provide for the required flexibility to reach the energy neutrality objective, while ensuring that the potential for renewable energy production and for energy savings is fully achieved, that objective should be met at national level and not for each treatment plant. Nevertheless, collecting evidence through case studies on energy consumption and energy production, including future potentials and projections, is of high relevance. The involvement of operators across the EU and the data collection will serve for different purposes:

- test the calculation methodology in each case study, investigating how the assumptions made in the methodology will affect the final results on energy neutrality.
- Support with evidence assumptions that need to be done to perform a European assessment of energy neutrality, exploring future possible scenarios at the European scale, generalizing the collected information.
- Provide reference cases at the European scale, showing how challenges and bottlenecks have been tackled, the exploited opportunities and the motivations that have made some operators successful, as well as the limitations that could make difficult to reach energy neutrality in certain contexts, exploring possible solutions.

In order to take into account of the national level of the target, which is not at single WWTP level, a case study is here mentioned as an ensemble of WWTPs, often managed by the same operator, or belonging to a certain area or MS. However, depending on data availability and willingness of operators, there are some case studies that only refer to specific WWTPs.

Table 1 shows the current state of the engagement with operators and the ones which have already provided a first draft on their current situation and a projected future one.

Table 1. List of case studies.

Country	number of case studies	comment
Italy	2	2 drafts provided from two operators
Denmark	1	draft provided, ensemble of all country
Slovenia	1	in progress
Belgium	2	1 draft provided, 1 in progress
Finland	1	1 draft provided
Sweden	1	1 draft provided
Greece	1	1 draft provided
Spain	1	1 virtual case discussed
Portugal	1	in progress
Romania	1	in progress
Cyprus	1	awaiting feedback
The Netherlands	1	in progress, ensemble of all country
Germany	1	In progress, ensemble of a large area

4. Methodology for the calculation of energy neutrality

In this section we discuss the issues to address when comparing energy use and energy production in a WWTP. It should be stressed that the following sections do not represent a recommendation of a methodology, but only an outline of aspects to discuss and take into account when developing a methodology.

4.1. General issues

4.1.1. Energy equivalence

Energy neutrality is meant as the equivalence of renewable energy generated to the energy consumed by all treatment plants treating a load of 10 000 p.e. and above. The Directive makes no distinction among forms of energy, hence in principle both thermal and electric energy used in UWWTPs should be accounted for, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas. Energy embedded in valuable products being produced (struvite, ammonia, EPS, Vivianite, biochar, dried sludge for the cement industry) should be counted only if used for energetic purposes, together with the energy consumption to produce them. Measures aimed at reducing energy consumption would also represent a win-win solution by reducing energy consumption.

When comparing the production and use of energy in UWWTPs, it is necessary to combine these different forms of energy.

In theory, heat and electricity should not be considered as equivalent, because the energy (usable energy) of heat is less than the energy of electricity. Combining thermal and electric energy based on their energy would entail reducing the thermal energy terms of the balance into "electric equivalents". This way is the most rigorous from a theoretical point of view. However, a significantly higher electricity value compared to heat would not incentivize the harvesting of thermal energy and the recovery of energy carriers (biosolids and biomethane), representing the peculiar energy sources within a wastewater treatment plant.

Interpreting energy neutrality as a requirement for electricity and heat separately would imply an undue burden for the operators, as plants tend to have a surplus of heat and a deficiency of electricity.

Considering electricity and heat as energetically fully equivalent ("one kWh is one kWh") would allow a complete compensation of surplus and deficit. This is the approach followed in the German (Bundesamt fur Wirtschaft und Ausfuhrkontrolle, 2024) and Danish (Ministry of Environment of Denmark, 2021) cases. By considering thermal and electric energy as equivalent, the operators are stimulated to reach energy neutrality by exploiting in the first place the thermal energy content of wastewater (for example, by cogeneration and/or heat pumps), and then by implementing measures like photovoltaics or wind farms. Moreover, if biogas is upgraded to biomethane, its full energy content can be accounted for as it will undergo use as fuel. Heat pumps can be used not only for heat generation, but also for cooling (district heating and cooling). To count towards energy neutrality, it is essential that the heat generated in the wastewater sector is actually used, i.e. it is not "waste heat". If this condition is met, the equivalence appears defendable.

4.1.2. Energy calculation and embedded energy

Some treatment processes may alternatively use energy on site, or inputs and chemicals embedding significant energy for their production. Table 1 lists the standard values of energy embedded in some chemicals of common use in wastewater treatment.

Table 1. Energy embedded in the production of some chemicals (equivalence in electricity, mix EU 2018, kWh/kg).

Chemical	Energy consumption (kWh/kg)
Acetic acid 80% sol.	10.3
Aluminium sulphate 50% sol.	1.04
Iron(III) chloride 40% sol.	3.40
Iron(III) sulphate 12.5% sol.	1.90
Iron(II) sulphate 100%	0.90
Methanol 100%	9.21
NaOH 50% sol.	4.17
Peracetic acid 15% sol.	6.90
Polyaluminium chloride (PAC) 25% sol.	1.94
Polyelectrolyte (polymer 5%)	1.40
Liquefied Oxygen	1.00

According to two WWTPs (600,000 and 1,100,000 PE), chemicals are used in the quantity of 3.7 and 2.8 kg/PE/year, respectively, with a supply chain energy of 13.8% and 21.3% of total energy consumption (including chemicals supply chain energy). An ensemble of WWTPs in Central Europe with 5,400,000 PE consumes 6.9 kg/PE/year of chemicals, which is up to 37% of total energy consumption (including chemical one).

4.1.3. "On-site or off-site" and "On behalf"

Art. 11 allows to consider for the goal of energy neutrality all generation of renewable energy irrespective of whether it is produced on-site or off-site. This implies that any compliant energy project developed by the owners or operators of WWTPs can be considered. If not possible, despites all measures identified under the audits and taken, there is the possibility to purchase a certain % of non-fossil fuel energy (up to 35%).

Examples of power generation off-site include development of hydropower stations, biomass plants or wind farms by the operators of the WWTPs, irrespective of where the energy is generated. In the calculation of energy neutrality, the energy produced off-site should not be double-counted, so e.g. energy produced in one EU MS by an operator from another MS should be included in the energy neutrality accounts of the MS where the operator is based.

The Directive allows the purchase of energy from renewable sources when it is not possible to 'produce/generate' enough energy from renewable sources despite all the measures identified by audits and implemented, but does not allow to account for purchased renewable energy in the part of renewable energy generated by or on behalf of the owners or operators. In order to be considered as produced "on behalf" of the operators, energy should be generated through dedicated plants developed specifically for the operators, including through power purchase agreements (PPAs).

Energy generated off site by wastewater owners/operators, whose core business areas include the sale of energy in quantities much larger than the needs of their plants (such as multi-utilites active both on the water and on the energy market), should not be taken into account for energy neutrality. Energy from these sources may be considered within the limits of 35% of non-fossil energy purchased from the grid already allowed by way of derogation in the Directive.

In case of on-site renewable energy generation produced by external firms, it can be counted if "on behalf" of the operator.

4.1.4. Wastewater effluent embedded energy

In order to count towards energy neutrality, energy can be recovered by any actor from any the materials and processes entailed in the wastewater treatment, be it on site or off site, such as sludge or wastewater effluent. The recovery of energy must be actual and not potential, i.e. the energy generated on site or off site must be used in a demonstrable way (sold or anyway metered). This also includes hydropower and heat pumps on the effluent operated by external actors, or PV installed by external actors on the area of competence of a WWTP, as WWTPs have been identified as a renewables go-to areas. Net energy should only be accounted, e.g. deducing electricity consumption of heat pumps or energy for the operation of the hydropower plant. Heat pumps using air should count only if owned and managed by the operator for self-consumption: in this case, they are already implicitly accounted because electricity consumption for their operation is counted, and their heat production would reduce heat imports, but heat that is produced by air heat pumps is also heat that is consumed. Net energy should always be considered.

4.2. Towards a methodology for energy neutrality accounting

The proposed methodology to calculate energy neutrality (EN) is based on the calculation of the ratio between annual renewable energy generation and total energy use. The following equation is proposed to compute energy neutrality:

$$EN = \frac{E_e+E_h}{C_e+C_h} \qquad \text{(Equation 1)}$$

where the subscript *e* stays for electricity and *h* for heat. Energy consumption *C* includes all energy used in the sludge and wastewater treatment, with the exceptions discussed below, while *E* includes all the renewable energy production, listed above, and considering the points below.

Sludge transport

Energy for transporting the sludge was quantified into 0.07 kWh/PE/y in Gothenburg region, Sweden (0.14% of total energy consumption), 0.06 kWh/PE/y in Greece (0.2% of total energy consumption), 3.31 kWh/PE in Slovenia (1.5%) and 0.85 kWh/PE/y in Flanders (Belgium, 1.6% of total energy consumption).

Sludge transport is very marginal and already optimized to minimize costs, it would not affect appreciably the energy balance, but its reduction would reduce other impacts, road clogging and emissions of CO_2 and NO_x.

Sludge drying

Sludge drying does not generally happen on the WWTPs, sometimes the sludge is just dewatered and more often it is dried at the incineration plant with the off-heat there, and for landfilling the sludge it not necessarily dried (only dewatered). In case the dried sludge is incinerated, internal energy of the dried sludge generally balances the energy consumption for its drying.

Influent pumping

Influent pumping often represents one of the largest energy consumption sinks, depending on the topography. In case energy for influent pumping is not measured, it should be estimated as $E=s*\gamma*V*H/\eta$, where γ=9800 N/m3, V is the pumped wastewater volume, H is the gross hydraulic head, η is the pump efficiency and s is the specific gravity of wastewater, that can be assumed equal to 1.02. Analogously for the effluent pumping to the receiving body.

Self-consumption and energy saving

In case of energy used for self-consumption, this should be considered as own energy generation at the numerator of Eq.1, and not as negative addendum to the denominator of Eq.1, in order to avoid division by 0 or very low denominators, resulting in extremely high energy neutrality ratios. For example, if one process consumes X kWh, and Y kWh are produced by own heat recovery system, or by the own CHP or photovoltaic panel, the consumption X goes at the denominator, why Y at the numerator, as long as Y is from renewable energy.

Any process aimed at reducing energy consumption (e.g., real time control) should count as reduction factor of energy consumption.

Thermal and electric energy of sludge

If the operator is the final user of the energy embedded in the sludge, e.g. if it is the owner of the incinerator, the thermal and electric energy to be considered is the one effectively used or sold, net of energy for treating the sludge and transporting it according to the above paragraph, including drying at the WWTP if implemented.

In case that the operator does not know the energy generation by its own sludge, the following mathematical approach can be followed, by Equation 2

$$E_{el,eq} = E_{int}\left(k_1\eta_{el} + k_2\,\eta_{th}(1-\eta_{el})\right) \qquad \text{(Equation 2)}$$

Where:

$E_{el,eq}$ = electrical energy equivalent

E_{int} = internal energy of the sludge delivered (i.e. energy embedded in the sludge net of energy for treating it). It can be assumed 3.3 kWh/kg of dry matter for dried digested sludge at 100%, to which energy associated to sensible heat and latent heat of water needs to be deduced, depending on water content. Energy for treating this sludge should be computed once, and not double counted in the energy consumption terms C of Eq.1.

η_{el}= electric efficiency of the incinerator (in the EU, maximum efficiencies reach 25%, but are generally in the range of 10-15% in case of CHP, ZWE (2023)); only if the real efficiency is not know, the default value is 15%, unless the real efficiency is above

η_{th}=thermal efficiency of the incinerator (80% only if unknown)

These default factors, to be used when the actual efficiency is unknown, should be corrected based on the annual average temperature and construction year as described in EC (2015).

$E_{el,eq}$ should consider that not all the heat produced by the incinerator might be used, and a certain percentage of produced heat (and, although less likely, even electricity) might be wasted (in addition to the process losses L). The coefficient $k_2=E_{th,ef}/(E_{th,ef}+E_{th,l})$, takes this into account, where $E_{th,ef}$ is the thermal energy effectively used or sold by the incinerator's owner over the reference period, $E_{th,l}$ is the wasted thermal energy. Analogously, $k_1=E_{elef}/(E_{el,ef}+E_{el,l})$, which is generally equal to 1.

When the sludge is exported, its net calorific value should be considered, i.e. the abovementioned E_{in}.

Thermal and electric energy of CHP for biogas

The same approach of *Thermal and electric energy of sludge* can be followed, but with default electric efficiencies (only in case of unknown) of 30% or 42% (for CHP units below 30 kW and above 250 kW, respectively) depending on the power size of the CHP (Arbeitsblatt DWA-A 216, 2015, EC, 2015), and used the effective biogas used volume net of leakages.

Imported/Exported gas

By gas we mean any type of gas, such as natural gas, biogas and biomethane. Gas can be imported from the grid, for example for heating purposes, but also exported, for example when biomethane is produced and used for the transport sector. Their contribution to the energy balance should be factored in by considering the calorific heat value (for example, for the imported natural gas, the flow rate multiplied by the calorific value per unit flow).

Reference year for the calculation

In order to avoid that the energy neutrality calculation is affected by an anomalous year (e.g., too wet or too dry), the energy neutrality ratio should be calculated over the past 4 years, in line with the energy audits. As a comparison, the calculation period of the Energy Efficiency Directive (EC, 2019) is three years.

5. Comparison with existing guidelines or legislation regarding energy neutrality

5.1. Denmark

...

5.2. Germany

...

6. Recommendations and conclusions

[outline of the final methodology here, including a flow chart]

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List of abbreviations and definitions

Abbreviations	Definitions
WWTP	Wastewater treatment plant
EU	European Union
MS	Member State
PE	Population Equivalent

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Annexes

Annex 1

Table 2. Energy consumption (kWh/m^3) in different processes, data from real WWTPs. k = thousand.

WWTP size	PE < 2 k	2 k < PE < 10 k	10 k < PE < 50 k	50 k < PE < 100 k	PE > 100 k
Number of WWTPs examined	3	6	18	13	36
Preliminary treatment					
Influent pumping		$2.2 \cdot 10^{-2}$	$3.9 \cdot 10^{-2}$	$4.2 \cdot 10^{-2}$	$4.1 \cdot 10^{-2}$
Micro screening			0.023		$4.2 \cdot 10^{-3}$
Screening	$1.3 \cdot 10^{-2}$	$3.8 \cdot 10^{-3}$	$1.4 \cdot 10^{-3}$	$1.0 \cdot 10^{-4}$	$2.9 \cdot 10^{-5}$
Comminutors			$3.9 \cdot 10^{-3}$		
Degritting		$1.1 \cdot 10^{-5}$	$6.6 \cdot 10^{-3}$	$5.4 \cdot 10^{-3}$	$2.7 \cdot 10^{-3}$
Primary – treatment					
Primary settling			$7.1 \cdot 10^{-3}$	$4.8 \cdot 10^{-3}$	$4.3 \cdot 10^{-3}$
Secondary treatment					
Trickling filter			$8.0 \cdot 10^{-2}$	0.14	0.18
Mixer anoxic		$5.3 \cdot 10^{-2}$	$6.8 \cdot 10^{-2}$	$7.0 \cdot 10^{-2}$	0.16
Mixed liquor recirculation		$1.0 \cdot 10^{-2}$		$4.7 \cdot 10^{-2}$	
Blowers oxidation	0.8	0.21	0.18	0.22	0.19
Mixer aerobic oxidation					$2.0 \cdot 10^{-3}$
Final settling		$1.2 \cdot 10^{-2}$	$5.5 \cdot 10^{-3}$	$7.1 \cdot 10^{-3}$	$8.4 \cdot 10^{-3}$
Sludge recirculation	0.23	$7.9 \cdot 10^{-2}$	$2.9 \cdot 10^{-2}$	$1.1 \cdot 10^{-2}$	$7.9 \cdot 10^{-3}$
Bio-filtration			$7.1 \cdot 10^{-2}$	$6.9 \cdot 10^{-2}$	$5.5 \cdot 10^{-3}$
Membrane Bio-Reactor			0.63	0.72	0.38
Sequential Bio-Reactor			0.22	0.29	0.15
Tertiary treatment					
Chemicals			$1.1 \cdot 10^{-2}$	$1.5 \cdot 10^{-2}$	$9.0 \cdot 10^{-3}$
Chlorine disinfection			$2.0 \cdot 10^{-4}$	$2.7 \cdot 10^{-4}$	$8.8 \cdot 10^{-4}$
Pump tertiary filtration			$2.9 \cdot 10^{-2}$	$5.9 \cdot 10^{-2}$	$1.4 \cdot 10^{-2}$
Tertiary filtration			$2.7 \cdot 10^{-2}$	$1.3 \cdot 10^{-2}$	$7.4 \cdot 10^{-3}$
Ultra-Violet lamps			$4.5 \cdot 10^{-2}$	$6.2 \cdot 10^{-2}$	0.11
Quaternary treatment					
Activated carbon					2-2.5 (kWh/PE)
Ozone Generation					15 – 23(kWh/PE)
UV disinfection					0.7-3.7 (kWh/PE)
Microfiltartion/Ultrafiltration					0.2-0.3
Reverse osmosis					0.46-0.6
Electrodialysis					1.1-2.2
UV photalysis					0.05-0.1
Sludge treatment					
Sludge primary settler			$1.7 \cdot 10^{-4}$		$1.8 \cdot 10^{-4}$
Excess sludge pumping		$1.6 \cdot 10^{-2}$	$4.5 \cdot 10^{-3}$		$7.3 \cdot 10^{-4}$
Gravity thickening	$9.2 \cdot 10^{-3}$	$3.7 \cdot 10^{-3}$	$2.7 \cdot 10^{-3}$	$2.1 \cdot 10^{-3}$	$1.9 \cdot 10^{-3}$
Centrifuge thickening			$1.6 \cdot 10^{-2}$	$1.5 \cdot 10^{-2}$	$1.8 \cdot 10^{-2}$
Floating thickening			$1.4 \cdot 10^{-2}$		$3.5 \cdot 10^{-2}$

Mixer aerobic stabilization		$2.6 \cdot 10^{-2}$			
Blowers aerobic stabilization	0.53	$4.5 \cdot 10^{-2}$	0.17	0.15	$2.4 \cdot 10^{-2}$
Anaerobic stabilization				$2.9 \cdot 10^{-2}$	$3.2 \cdot 10^{-2}$
Motor gas recirculation			$1.9 \cdot 10^{-2}$		$3.1 \cdot 10^{-3}$
Heating sludge			$3.5 \cdot 10^{-3}$		$2.4 \cdot 10^{-3}$
Vacuum filter			$1.5 \cdot 10^{-2}$		$9.8 \cdot 10^{-3}$
Incineration			$1.2 \cdot 10^{-2}$		$0.7 \cdot 10^{-3}$
Centrifuge dew		$1.8 \cdot 10^{-2}$	$2.0 \cdot 10^{-2}$	$2.3 \cdot 10^{-2}$	$2.7 \cdot 10^{-2}$
Belt filter press				$1.2 \cdot 10^{-2}$	$1.0 \cdot 10^{-3}$
Screw press			$4.0 \cdot 10^{-3}$	$4.8 \cdot 10^{-3}$	$4.9 \cdot 10^{-3}$
Fermentation			$3.0 \cdot 10^{-2}$	$9.5 \cdot 10^{-3}$	$1.6 \cdot 10^{-4}$

Annex 2

Pyrolysis

Roslagsvatten AB is planning to implement a new sludge treatment solution at the Margretelund wastewater treatment plant (WWTP) in Österåker Municipality, Sweden. The project involves the installation of a pyrolysis facility treat sewage sludge. Currently, the Margretelund WWTP serves a population equivalent (pe) of approximately 35,000 and generates around 2,500–3,000 tons of dewatered sewage sludge per year, with a dry solids (TS) content of about 25%. The planned pyrolysis unit is designed to handle this full volume, with a capacity to treat up to 800–1,000 tons of dry matter annually.

Wind farms

Three wind turbines with a total installed capacity of 8.6 MW, and producing up to 23,000 MWh of electricity annually, are now in operation in Dradenau, Hamburg WWTP. The electricity from the new wind turbine will be used supply the wastewater treatment plants themselves. Surpluses will be fed into the Hamburg power grid. In addition to planned photovoltaic installations, the expanded sewage sludge incineration plant will increase electricity and heat production. Hamburg Wasser is also planning three more digestion towers to produce sewage gas of natural gas quality for the city's gas grid. A new 180-metre-high forth wind turbine is also planned and will produce 3.6 MW of power and up to 9,000 MWh of renewable electricity per annum, bringing the company closer to its goal of energy self-sufficiency by 2030. Also, located in Amsterdam's main wastewater treatment plant, four wind turbines are generating renewable energy. The turbines were erected using a 160-metre-high crane. The four turbines, together, generate 21,000 MWh of electricity per year – equivalent to the annual consumption of 10,000 households in Amsterdam. The four wind turbines are the first of a scheduled 17 new turbines that the City of Amsterdam is planning to install in the coming years.

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