Im Auftrag des:

Measures to save energy and reduce greenhouse gas emissions at municipal and industrial wastewater treatment

Report 2

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1 Greenhouse Gas (GHG) balance

1.1 General

Worldwide progress goes hand in hand with the steadily increasing use of energy - in 2009 approx. 20,700 kWh per person were used. Around 80% of this energy comes mainly from the combustion of fossil carbons (oil, gas, coal). The consumption of these finite raw materials has a direct impact as CO_2 is an end-product of combustion. [1]

The effects of the increasing proportion of CO_2 in the atmosphere are dealt with in the various climate models. The basis of the political decision is the requirement not to exceed the global temperature increase of 2°C in order to prevent incalculable scenarios as far as possible. [1] One of the European Union's climate key targets for 2030 are reduce greenhouse gas emissions at least 40% compared to 1990 levels and improvement energy efficiency at least 32,5% [2].

In 2005, the CO_2 certificate trade was launched: from 2013, this trade became an important cost factor for industry, as the quantity of certificates decreased by 1.74% annually. In 2021 the cap on emissions also continues to decrease annually at an increased annual linear reduction factor of 2.2% to increase the pace of emissions cuts (period 2021-2030). [3] This issue has given rise to a clear will to act within companies and corporations: the carbon footprint (CF) has become a buzzword and many companies are committed to reducing the carbon footprint. Energy-saving measures are presented in terms of their impact on carbon footprint. [1]

Wastewater treatment is recognised as a production site for biogas, which can be used as a CO_2-neutral substitute for fossil fuels. So anaerobic wastewater treatment technology offers great advantages, which are also seen by industries, that have previously relied on aerobic wastewater treatment in a consistent manner. [1]

1.2 Framework

Humans are increasingly influencing the climate and the earth's temperature and this adds enormous amounts of greenhouse gases to the naturally occurring atmosphere. Based on the evaluation of many years of measurement series it can referred entirety as “climate change”. The so-called greenhouse gases (GHGs) have been identified as the main causes of global warming. The GHGs, essentially naturally occurring H_2O (as water vapour, approx. 4% of the atmosphere’s composition) and the human-caused greenhouse gases CO_2, CH_4, N_2O, fluorocarbons (in total <1% of the atmosphere’s composition), are very effective in their greenhouse effect. [1]

For several decades, anthropogenic emissions of GHGs have been increasing significantly, especially CO_2. At 64%, the majority of it comes from the combustion of fossil sources, with about 41% each from oil and coal, and 23% from gas [4]. Methane (CH_4) and nitrous oxide (N_2O) are also very potent GHGs, and their impact in this respect is significantly greater than that of CO_2. They have been released mainly from agriculture: their origin from wastewater treatment is lower. However, technical approaches to avoid greenhouse gases release must be pursued further so that the increased conversion of organic carbons through anaerobic processes results in a positive overall carbon footprint balance. [1]

1.3 Carbon Footprint

Carbon footprint refers to the sum of all GHGs caused directly or indirectly by a person, an organisation, the implementation of an event, an occurrence or the manufacture of a product. The product carbon footprint describes the balance of GHG emissions along the entire life cycle of a product in a defined application and in relation to a defined unit of use. GHG emissions are all those gaseous substances for which the Intergovernmental Panel on Climate Change (IPCC) has defined a coefficient for the global warming potential (GWP). The life cycle of a product encompasses the entire value chain: from the manufacture and transport of raw materials and intermediate products, through production and distribution, to use, after-use and disposal. The term product is a generic term for goods and services. [1]

Carbon footprint is an indicator that is integrated into a single figure and is usually expressed as Mg CO_2 equivalent (CO_2eq). The effects of other climate-relevant gases are included in the equivalent; relevant here are methane and nitrous oxide. The impacts are generally calculated for a period of 100 years, as the residence times in the atmosphere vary considerably. The equivalent values refer to the CO_2 potential, which is set to "1". Accordingly, methane has a potential of 28 and nitrous oxide a potential of 265. [5] This means that over a period of 100 years, 1 Mg of methane gas has the same impact on the climate as 25 Mg of CO_2. The requirements for future wastewater treatment thus include not only the reduction of CO_2 emissions, but on an even larger scale, the prevention of the release of methane and nitrous oxide. [1]

1.4 Methodology

Based on the definition of the carbon footprint and the conversion of other GHGs to CO_2 eq of fossil fuels can be said to depend on the fuel, amount of fuel consumed and the generation of electrical energy. The last comparison shows large regional differences that have a considerable impact on the calculation. Figure 1.4.1 illustrates the emission of CO_2 equivalents in the generation of electrical energy in a continents comparison. The decisive factor here is also the type of primary energy used.

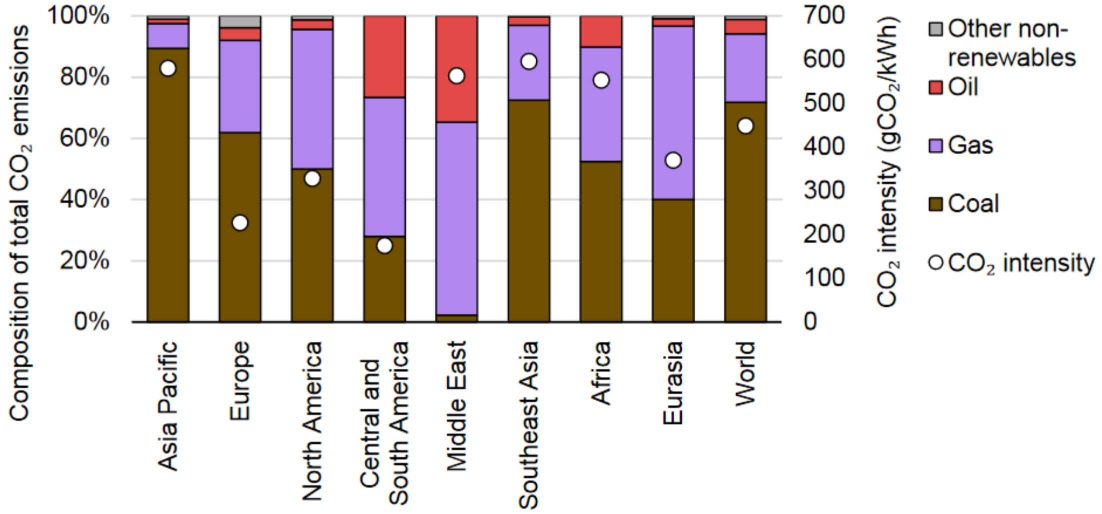


Figure 1.4.1. Composition of CO_2 emission and emission intensity in 2020 [6]

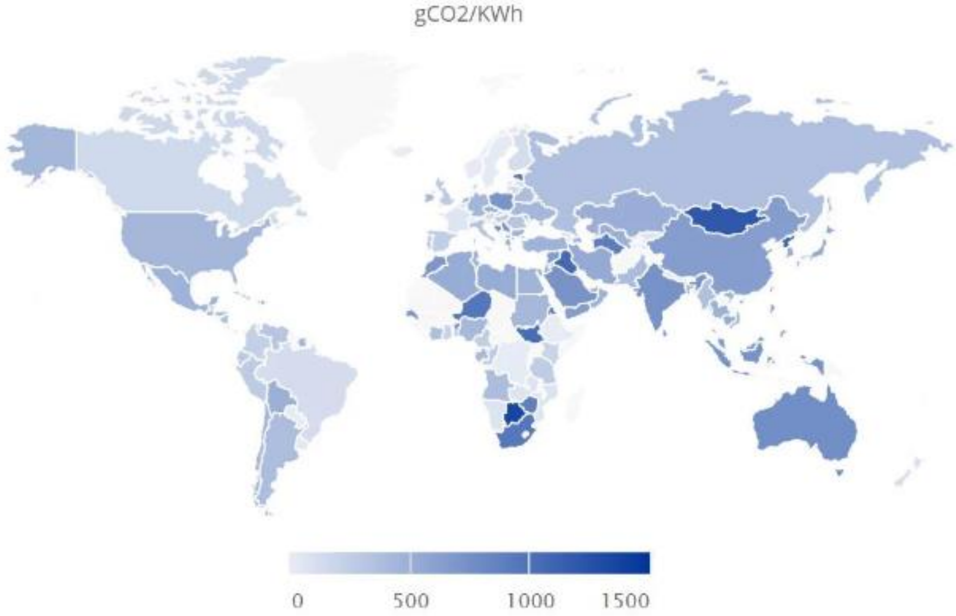


Figure 1.4.2. Emitted CO_2 emission to produce one kWh of electricity in 2016 [7]

The size of the scope of consideration is central to the carbon footprint, and a distinction is made between direct and indirect emissions [1]:

- direct emissions originate from sources in the direct area of responsibility, typically a production facility or a wastewater treatment plant,
- indirect emissions result from the operation of a production or treatment facility, but they occur elsewhere.

The carbon footprint (CF) is calculated from the summation of the associated individual activities [1].

$$CF = \sum_{i=l}^{n} A_i \times FE_i \quad (1.1)$$

where, i is the run parameter of the individual activities;
A_i is the consumption (m^3 of gas, Mg of steel, tonne-kilometres of freight etc.);
FE_i is the specific CO_2 eq emission factor for the respective consumption.

Specific emission factors have been collected for many different areas, such as materials, energy sources and manufacturing processes. An overview is shown in Figure 1.4.3 [1]

A large number of countries have developed their own database of these emission factors. Europe-wide calculation bases are under development. However, the magnitudes of the individual factors are very comparable and the conclusions as to which are the essential factors result in identical parameters. It is worthwhile to first make a rough estimate and then look more closely at the summands with the largest proportions. [1]

For the operation of wastewater treatment plants, the daily consumption of electrical energy is the determining factor. The emission factor varies greatly depending on the energy sources used in a country (see Figure 1.4.2). As a result, plants of the same design produce very different CO_2 emissions depending on their location. [1]

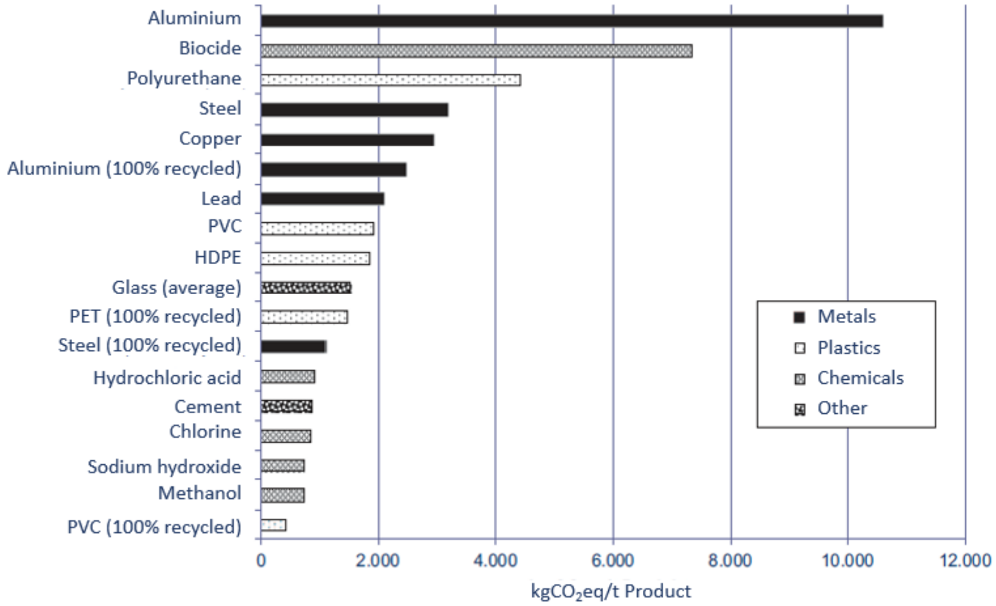


Figure 1.4.3. Specific emission factors [1]

The following factors are typically taken into account in the calculation for the construction and operation of a plant and represent the indirect emissions [1]:

- goods and materials used in construction, expressed in Mg or €,
- transport of these materials in Mg - km, differentiated by transport type,
- travel activities of those involved in the construction,
- chemicals used in operation in Mg, plus associated transport,
- operating energy in kWh, differentiated by type of energy,
- waste and GHGs generated during operation,
- other operating materials in Mg or €, plus associated transport.

The operating time on which the calculation is based is defined as the economic service life. For industrial wastewater treatment plants, this is often estimated at 20 years. The dismantling of a plant after the end of the economic service life is excluded from the consideration, as too many unknowns would have to be included here, which would not achieve the required accuracy of the results. [1]

In addition, there are direct emissions from the plant operation. These are essentially the GHGs released during biodegradation (CO_2, CH_4, NO_x). The associated CO_2 eq should be included in the calculation if they are known in terms of quantity. If no reliable data is available, it should be stated which gases were not taken into account. For international use, it has proven useful to set up the database used for the emission factor approach as broadly as possible (ADEME, EcoInvent, ICE, EPA etc.) and to transfer it to a common database. This approach can effectively fill data gaps if local data is not available or only insufficiently available. For Germany, a DIN-ISO standard on this topic is in preparation, which will contain the valid emission factors. [1]

In return, emissions are also avoided, especially the energy savings from the use of biogas. When calculating the savings, the same factors should be applied that were used for the use of primary energy, be it for direct thermal use or the generation of electrical energy, because this primary energy is substituted. The reductions in the carbon footprint resulting from the reuse of input energy, e.g., from waste heat, should be presented separately. [1]

The calculation of the Carbon Footprint is not an exact science, as the individual activities, and especially the various emission factors, have a limited calculation depth or are based on assumptions. The uncertainty factors are part of the respective data base used and can be included in the calculation. In any case, the goal is to set up a calculation model in which different process technologies can be compared on a common basis. [1]

1.5 Case study Schollershammer Paper Mill

The Schoellershammer paper mill wastewater treatment plant is located in Germany and produces 200,000 Mg/a of corrugated base paper. Wastewater is treated in a biological anaerobic/aerobic wastewater plant – what combines the anaerobic stage with a conventional activated sludge plant for secondary treatment. [1]

The anaerobic process used according to the BIOBED® EGSB technology uses anaerobic pellet sludge for the pre-treatment of the highly concentrated industrial wastewater. The organic wastewater constituents are converted into biogas in this process. The biogas utilisation neutralises the carbon footprint of the wastewater treatment plant and also has a low carbon footprint. The biogas produced is utilised in a combined heat and power (CHP) plant. The BIOBED® plant is designed for a wastewater volume of 2,880 m^3/d and a COD load of 14 Mg/d. The reactor has a volume of 800 m^3 and produces about 5,000 m^3/d of biogas. This is utilised in two CHP units with an electrical output of 350 kW each. For the secondary treatment of the wastewater, an activated sludge plant is installed, consisting of an activated sludge tank with a volume of 1,200 m^3 and a secondary sedimentation tank (diameter 13 m). Half of the surplus sludge is incinerated, and half landfilled. [1]

The case study has been prepared by Aquantis GmbH in order to determine the carbon footprint of an anaerobic/aerobic wastewater treatment plant typically used for industrial applications. The assessment limits in the calculation of the carbon footprint of the Schoellershammer WWTP include the construction and operation of the plant as well as the sludge disposal and the use of biogas. The carbon footprint associated with construction also includes the resources used to produce the materials, as well as their transport and processing. Electricity, chemicals and transport and disposal of sludge are part of the operational carbon footprint. This also includes the materials and equipment required for repair. The operational carbon footprint was calculated for an operating period of 20 years. Dismantling and disposal of the plant was not part of the calculation.

Consumed and generated electrical energy was calculated using the average emission factor for Germany of 0.44 kg CO_2 equivalent per kWh. For the calculation of the carbon footprint of the plant, Eq. 1.1 was used. The first step in calculating the carbon footprint is to record the activities associated with the construction and operation of the plant. When considering a plant technology for the first time, the aim should be to record all activities as completely as possible. Special attention should be paid to quantitatively dominant activities (e.g., energy and chemical consumption) and those activities that have a high emission factor (e.g., methane losses). [1]

The individual activities were then assigned the corresponding emission factors from the Veolia Water Technologies database. It has proven useful to group similar activities together. It allows for a better presentation as well as enables a quick identification of the main emission sources. The grouping is not standardised and can be adapted to the specifics of the plant or technology under consideration. [1]

A separate presentation of generated and, if applicable, avoided emissions is recommended. Furthermore, the emissions generated during the construction of the installation should be recorded separately. This makes it possible, in the case of comparable technology, to include these emissions in the calculation using a flat-rate approach and avoids the laborious recording of all activities carried out during construction. In the case of industrial wastewater treatment plants, it has been shown that the one-off GHG emissions generated during construction are negligible compared to the emissions generated during 20 years of plant operation and rarely exceed 5% of the total emissions. [1]

With some experience in calculating the carbon footprint of comparable facilities, the carbon footprint of a facility can be calculated very quickly and with sufficient accuracy based on a few emission-relevant activities and flat-rate approaches, e.g., for the construction of the facility. The carbon footprint calculation should be reviewed regularly to take into account changes that have occurred in the operation of the facility. For example, optimising the chemical requirements of a plant can result in a significant reduction of the carbon footprint. The result of the calculations is based on the operating results of the first year, which are broken down into the areas mentioned in Table 1.5.1.

Table 1.5.1: Schoellershammer wastewater plant: CO_2 emissions in 20 years [1]

Observation over 20 years	Mg CO_2 eq
Installation	750
Operation - Energy	13.024
Operation - Chemicals	5.800
Operation - Consumables	180
Operation - Maintenance	271
Operation - Process	6.110
Operation - Transport	92
Operation - Service	132
Operation - Other	2.200
Emissions avoided	− 31.240
Total Construction	750
Total operation	27.809
Total emissions	**28.559**
Total avoided emissions	**− 31.240**
Project emissions	**− 2.681**

The result shows that compared to the operational carbon footprint, the CO_2 emissions generated during the construction of the Schoellershammer wastewater plant are negligible. The operational carbon footprint is mainly caused by the electricity demand and the chemicals consumed, e.g., caustic soda for wastewater neutralisation. The third major source of CO_2 emissions is dissolved methane, which is released from the effluent of the anaerobic treatment stage and is recorded under "operating process". Although only about 13 mg/l methane are contained in the wastewater due to the low solubility of methane under the present operating conditions, the CO_2 equivalent of 25 results in a correspondingly high effect on the carbon footprint. [1]

The carbon emissions add up to about 28,500 Mg CO_2 equivalent over the lifetime of the plant. Due to the utilisation of the biogas in the CHPs and the electrical energy generated here, emissions of about 31,000 Mg CO_2 equivalent are avoided over the same period. In summary, it can be said that the Schoellershammer wastewater plant, which has been supplemented with an anaerobic stage, is CO_2-neutral. [1]

2 Energy efficiency

An evaluation of process technologies for the purification of highly organically polluted wastewater on the basis of primary energy consumption requires comprehensive balancing. In addition to the electricity (and heat) consumption usually considered at wastewater treatment plants, energy is also used in the production of machines and building materials. Therefore, a cradle-to-grave approach is necessary to generate a realistic overall picture. Depending on the objective and process technology, different levels of detail must be aimed for in the balancing in order to calculate comparative values with a reasonable effort. [8]

The balance limit, within which CO_2 and energy flows are taken into account, is of great importance for the comparability of the results. The "cradle-to-grave" approach takes the entire life cycle of the plants into account. However, various studies have shown that dismantling only plays a subordinate role. The main emissions in wastewater treatment plants are caused by the energy demand. [8]

The following chapters will throw light on energy check and analysis, as well as some state-of-the-art technologies that could be employed for reducing GHG emissions.

2.1 Energy consumption at wastewater treatment plants

In technical literature, numerous characteristic values have been introduced for determining, identifying and evaluating the energy efficiency of wastewater treatment plants, some of which are also used with different meanings.

An essential element of the various recommendations for action on energy optimisation published in recent years is the comparison of the resident-specific electricity consumption of the entire wastewater treatment plant or individual subareas in kWh/(I.a) with characteristic values (Table 2.1.1). The characteristic values used (ideal, guideline, tolerance, target, setpoint or average value) indicate a roughly comparable level but were derived differently. Basically, a distinction can be made between characteristic values which were derived [9]:

- from statistical surveys (tolerance and target value),
- from process engineering calculations of a model sewage treatment plant (ideal value),
- from the so-called best-practice principle (target value, guideline value).

In the past, energy studies were rarely carried out in the area of wastewater discharge. This was usually justified by the fact that the energy consumption of these plants was rather low compared to sewage treatment plants. For this reason, there are hardly any evaluations for this area as far as energy consumption is concerned. The main potentials for reducing energy consumption in wastewater discharge lie on the one hand in the optimisation of pumping stations and on the other hand in the conceptual design of urban drainage. The reduction of wastewater volumes, the optimal choice of drainage systems, a depth-optimised arrangement of drainage pipes and the like are difficult to realise in existing systems. However, these aspects of energy-optimised planning should be given greater consideration in the redesign of urban drainage systems, in addition to the familiar planning requirements. The ATV-DVWK-A 134 worksheet provides corresponding information. [9]

Table 2.1.1. Statistical evaluation of the energy analyses on the per capita electricity consumption promoted in the state of North Rhine-Westphalia categorised by wastewater treatment process

Process Group	Number	Specific electricity consumption (kWh/ (I.a))		
		Frequency of undercutting		
		25%	50%	75%
Total consumption	*n* = 91	32,0	42,0	53,5
Mechanics, total	*n* = 84	1,0	1,8	3,6
Rake	*n = 80*	0,1	0,1	0,3
Grit chamber	*n* = 81	0,5	0,9	2,1
Primary sedimentation	*n* = 61	0,1	0,3	0,5
Biological stage, total	*n* = 85	18,0	24,5	31,3
Aeration	*n* = 70	11,4	15,1	19,9
Recirculation	*n* = 66	2,3	3,7	6,3
Recirculation	*n* = 38	0,9	1,8	2,7
Return sludge pumping	*n* = 60	1,7	2,6	5,5
Effluent lift station	*n* = 59	2,0	3,3	5,0
Filtration	*n* = 27	2,7	3,8	6,1
Sludge treatment, total	*n* = 82	3,4	4,7	6,6
Pre-thickening	*n* = 53	0,1	0,6	1,1
Stabilisation/digestion	*n* = 58	1,9	2,7	4,5
Post-thickening	*n* = 19	0,05	0,1	0,2
Dewatering	*n* = 62	1,1	1,6	2,4
Other	*n* = 22	0,4	1,0	1,8
Infrastructure, total	*n* = 83	1,6	2,9	5,0
Ventilation	*n* = 18	0,2	0,7	1,4
Electric heating	*n* = 23	0,3	0,7	1,9
General (lighting, etc.)	*n* = 61	0,4	0,7	2,0
Domestic hot water	*n* = 24	0,2	0,4	0,8
Other	*n* = 49	0,4	1,3	2,8

The recording and optimisation of the energy efficiency of wastewater plants is carried out in two steps with different processing depth and objectives [9].

Step 1: Regular conduct of an energy check

The energy check is a regular energy inventory of a wastewater system based on a few characteristic values that can be determined by the operator himself. The energy check is carried out by comparison with undercutting frequencies that illustrate the range of the determined characteristic values on the basis of real operating data.

The undercutting frequencies are outlined in the Figure 3.1.1 to Figure 3.1.9 for the characteristic values of the energy check and thus serve as an initial orientation. If the corresponding characteristic value for the energy consumption of a plant is in the unfavourable range, it can usually be assumed that optimisation measures can be identified. The same applies to energy production (digester gas production, self-sufficiency).

As a rule, the energy check should be carried out annually (eg, as part of self-monitoring, benchmarking or to illustrate progress made in the meantime). Conclusions about the energetic development of the plant can be drawn from the development of the characteristic values over time. Furthermore, the need for an energy analysis can be derived from the characteristic values.

Step 2: Development and drafting of an energy analysis

The aim of the energy analysis is to carry out a detailed energy analysis of the wastewater plant and, based on this, to achieve an energy improvement of the plant operation. Compared to the energy check, the energy analysis requires a much more comprehensive and in-depth consideration of the wastewater plant, taking into account the machine, process, procedure and construction technology.

In the energy analysis, the elements of the energy check are expanded to include:

- a systematic, detailed survey of the energy demand in relation to aggregates, aggregate groups or plant components within the framework of an energy balance,
- an evaluation of the energy situation by comparing the actual values with plant-related ideal values,
- a presentation of concrete measures for energy optimisation with a comparison of the cost framework with the saved energy and operating costs.

Plant-related ideal values serve to describe an optimal range of energy use. They are calculated as part of the energy analysis for an optimal mode of operation and take into account design or process-related boundary conditions that are virtually unchangeable (e.g., wastewater composition) or cannot be changed with economically justifiable effort (e.g., delivery head of pumping stations).

3 Inventor and benchmarking

Energy check Energy check and energy analysis according to DWA-A 216.

3.1 Energy check

The purpose of the energy check is to take stock of the energy consumption of a wastewater treatment plant and to determine its initial position with regard to energy consumption and energy generation. The energy check is to be understood as a means of energy self-assessment and is therefore designed in such a way that it can be carried out by the operator himself on the basis of a few characteristic values.

The most obvious deficits can be identified from the results of the energy check, but without reliable quantitative statements and without detailed determination of causes. This is provided by the energy analysis. Within the scope of the energy check, only a few relatively simple energy parameters are determined. Values that are relatively easy to determine. Table 3.1.1 summarises the characteristic values. Basically, a distinction must be made between sewage treatment plants with digestion and those without digestion.

Depending on the individual plant technology and the availability of data, the scope of the characteristic of the characteristic values of the energy check can be supplemented. Decisive for the success of the energy check are the quality of the data basis and the clear definition of the system boundary.

Table 3.1.1. Characteristic values of the energy check [9]

Formula Symbol	Unit	Designation of Characteristic Value	Formula	Definition
Wastewater Treatment Plants				
e_{tot}	kWh/(I.a)	Specific total power consumption of the system	$e_{tot} = \frac{E_{tot}}{PE_{COD}}$	E_{tot} power consumption entire system in kWh/a PE_{COD} Population equivalent based on 120 g/(I·d) COD
e_{Aer}	kWh/ (I.a)	Specific power consumption of aeration*)	$e_{Aer} = \frac{E_{tot}}{PE_{COD}}$	E_{Aer} Power consumption aeration in activated sludge basin in kWh/a PE_{COD} Population equivalent based on 120 g/(I·d) COD
Wastewater Treatment Plants with Digestion				
e_{DG}	l/(I·d)	Specific biogas production based on the population equivalent	$e_{DG} = \frac{Q_{DG,d,aM}}{PE_{COD}}$	$Q_{DG,d,aM}$ annual average digester gas generation under standard conditions (l/d) PE_{COD} Population equivalent based on 120 g/(I·d) COD
Y_{DG}	l/kg	Specific biogas production based on volatile solids	$Y_{DG} = \frac{Q_{DG,d,aM}}{B_{d,VS,aM}}$	$B_{d,VS,aM}$ annual average of the volatile solids to the digester in kg/d

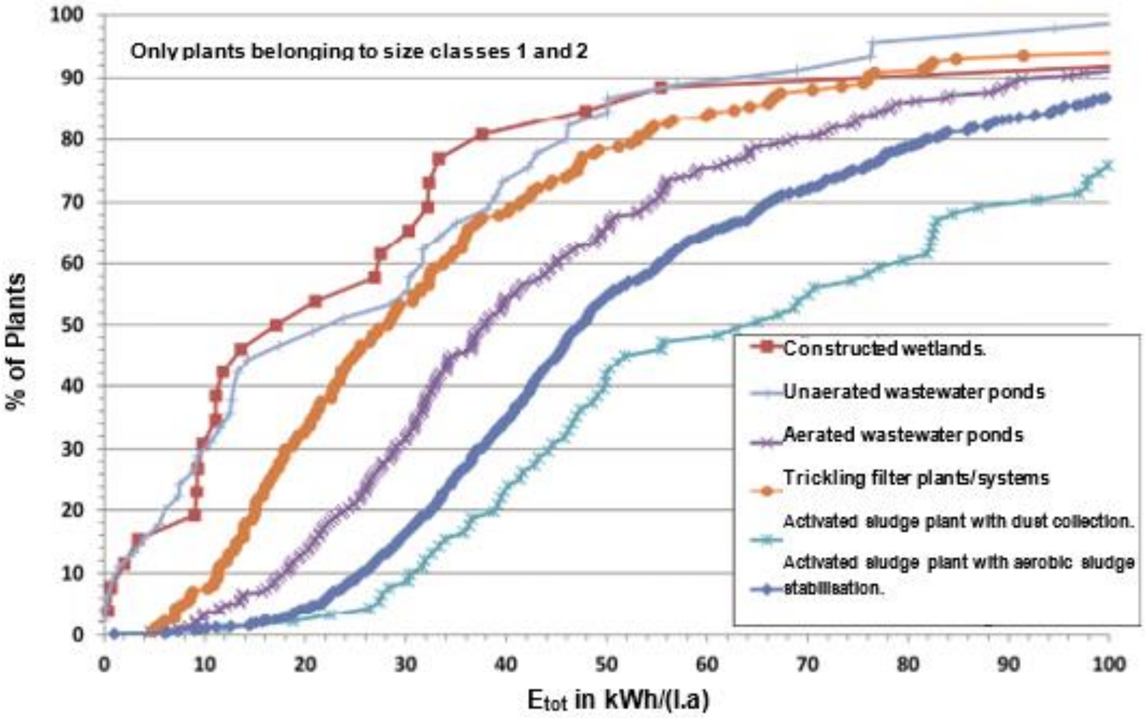
Formula Symbol	Unit	Designation of Characteristic Value	Formula	Definition
N_{DG}	%	Degree of digester gas conversion to electricity	$N_{DG} = \frac{E_{CHP,el} \cdot 100}{Q_{DG,a} \cdot g_{CH4} \cdot 10}$	$E_{CHP,el}$ Annual production of electricity from digester gas conversion in CHP plants or direct drive of aggregates in kWh/a $Q_{DG,a}$ Annual sum of digester gas generation under standard conditions in m^3/a g_{CH4} Volume share of methane in the biogas volume (1) (e.g., 0.64)
EV_{el}	%	Degree of self-sufficiency in electricity	$EV_{el} = \frac{E_{CHP,el} \cdot 100}{E_{tot}}$	$E_{CHP,el}$ Annual production of electricity from digester gas conversion in CHP plants or direct drive of aggregates in kWh/a E_{tot} total electricity demand in kWh/a
$e_{th,ext}$	kWh/(I.a)	Specific external heat consumption	$e_{th,ext} = \frac{E_{th,ext}}{PE_{COD}}$	$E_{th,ext}$ energy supplied externally for heat supply in kWh/a (fossil fuels) PE_{COD} Population equivalent based on 120 g/(I·d) COD
Pumping Station				
e_{PW}	Wh/(m³.m)	Specific power consumption of the pumping station	$e_{PW} = \frac{E_{PW,} \cdot 1000}{Q_{PW} \cdot h_{man}}$	E_{PW} power consumption of the pumping station in kWh/a Q_{PW} flow rate in m^3/a h_{man} is manometric head in m
NOTE **) If necessary measured values are available.*				

For initial orientation, the determined characteristic values can be put into relation with the associated undercutting frequencies (Figure 3.1.1). It should be taken into account that in Germany the data availability of the specific total electricity consumption of wastewater treatment plants is good. For the other key figures, there are currently significantly fewer accessible data sets. Therefore, no differentiation was made in Figure 3.1.3 to Figure 3.1.9 with regard to the size class of wastewater treatment plants.

The undercutting frequency of the specific total electricity consumption (Figure 3.1.1) is based on data material from the DWA performance comparison of municipal wastewater treatment plants (DWA 2013). The undercutting frequencies in Figure 3.1.3 to Figure 3.1.9 are based on a data collection in the states of Hamburg, Berlin, Schleswig-Holstein, Baden-Württemberg, Brandenburg and Bavaria, as well as on the provision of operating data from various cities and towns.

3.1.1 Specific total energy consumption

In the case of the key figures for electrical energy consumption, data with a higher undercutting frequency very probably indicate a potential for optimising energy use. The undercutting frequencies of the data collected from municipal wastewater treatment plants show a dependence of the specific total electricity consumption e_{tot} on the process technology used, especially in the case of smaller WWTP.



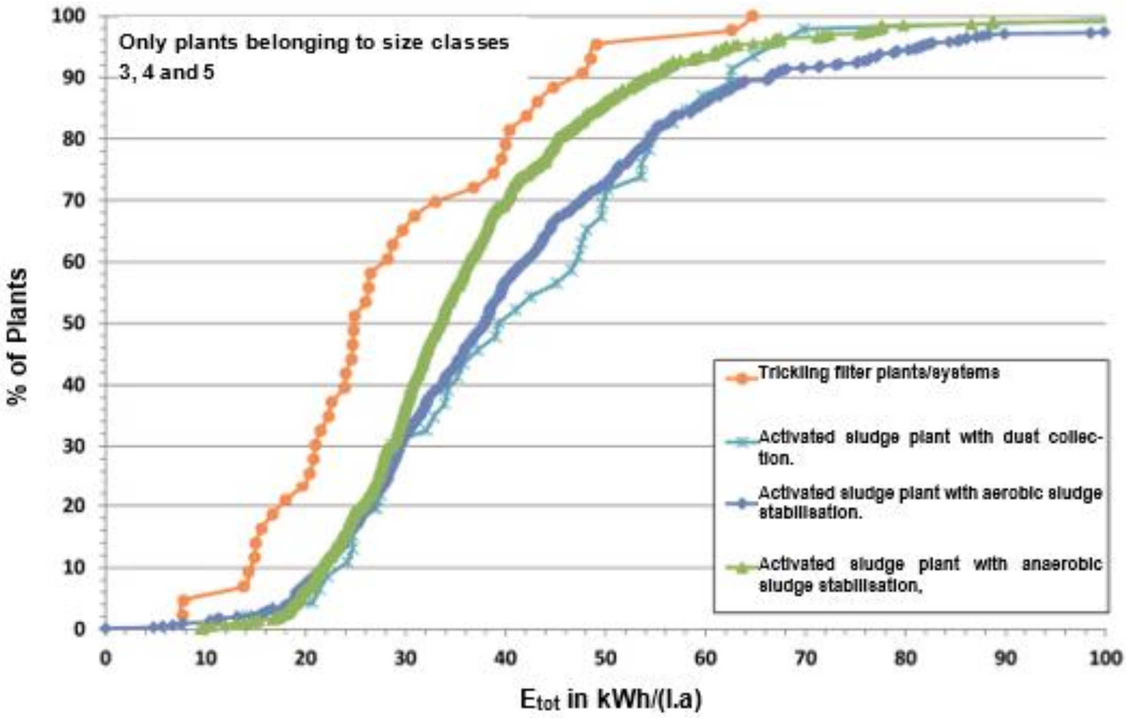


Figure 3.1.1 and Figure 3.1.2. Specific total electricity consumption depending on the cleaning process [9] (size classes: Class 1 <1 000PE, Class 2 <5000PE, Class 3 <10 000PE, Class 4 <100 000PE, Class 5 >100 000PE).

3.1.2 Specific electricity consumption for the aeration

Since the electricity consumption of the activated sludge plant (energy input for aeration/blower, circulation, recirculation, return sludge transport) is costly in practice and can usually only be determined in an in-depth energy analysis, the Energy Check directly targets the largest consumer in this area by introducing a specific electricity consumption for the aeration of the activated sludge tank e_{Aer}. This characteristic value, regularly determined over several years, provides information about the condition of the aeration system, especially about the condition of the aeration elements.

Since in the course of the operating time of the aeration of a wastewater treatment plant the input efficiency decreases due to material ageing and/or deposits on the aerators (scaling, fouling), the characteristic value provides information on the necessary cleaning of the aerators or on a decreasing efficiency of the blower. If the impairments are irreversible, it can be ensured in this way that the right time for an energy-related renovation of the aeration is recognised.

At sewage treatment plants with digestion, the production of digester gas is described by the inhabitant-specific digester gas production e_{DG} (l/(I.d). If the figures are reliable, the technically more meaningful reference to the added organic dry matter Y_{DG} (l/kg) should also be used. This applies especially if co-substrates and/or foreign sludges are assumed.

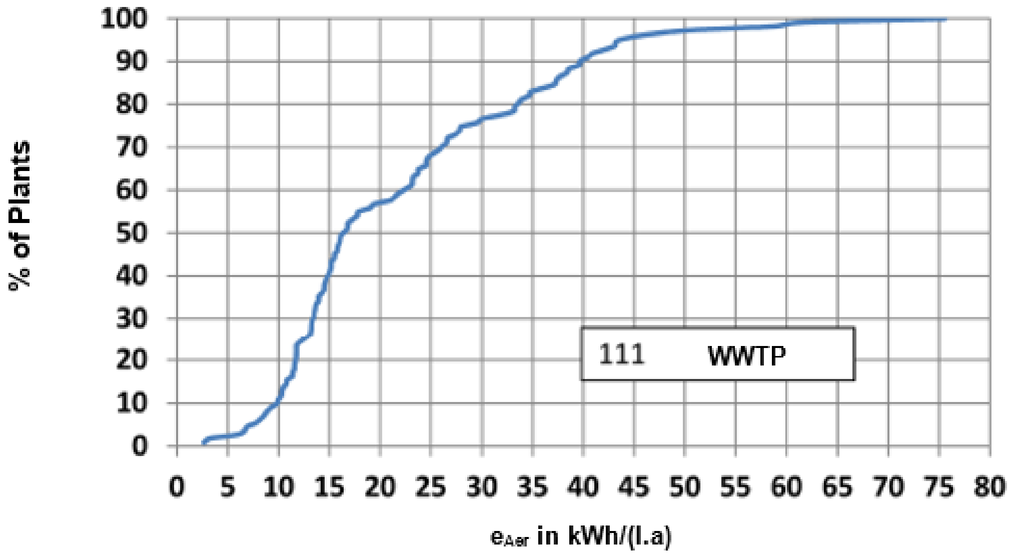


Figure 3.1.3. Specific electricity consumption for the aeration e_{Aer} of the wastewater treatment plants [9]

3.1.3 Specific digester gas

The population specific digester gas generation shown in Figure 3.1.4 is above the value range of the DWA regulations for many plants (see codes of practice DWA-M 368, DWA-M 264), because in the data material on which the graph is based, sewage treatment plants with the assumption of extraneous sludge and/or co-substrates were taken into account. The influence of the assumed co-ferments is also particularly evident in Figure 3.1.5. The transfer of external surplus sludge can be taken into account by referring to the organic dry matter added to the digester, but the higher gas yield per kilogram of organic dry matter from co-substrates (e.g., grease trap contents) leads to specific gas yields beyond the maximum 480 l/kg achievable with conventional municipal raw sludge (see DWA-M 264:2015).

In the case of the key figures for digester gas production/utilisation, a corresponding optimisation potential can be assumed if the own key figure is to be found in the lower range of the undercutting frequency. The parameter Degree of digester gas conversion to electricity N_{DG} (%) describes what proportion of the energy present in the digester gas was converted into electricity in a CHP plant. Factors influencing the N_{DG} (%) parameter are the proportion of digester gas converted to electricity and the electrical efficiency of the CHP plant. Ideally, all of the digester gas should be used to generate electricity. This complete utilisation may be limited by inspection and maintenance work on the CHP units. Furthermore, a non-uniform gas accumulation in combination with a non-existent or too small gas storage leads to gas losses through flaring.

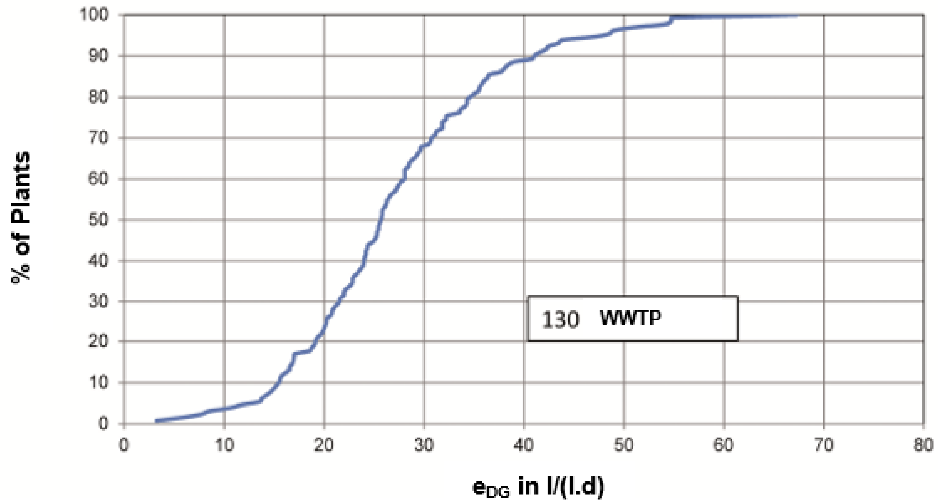


Figure 3.1.4. Specific digester gas production e_{DG} in relation to the connected population equivalents [9]

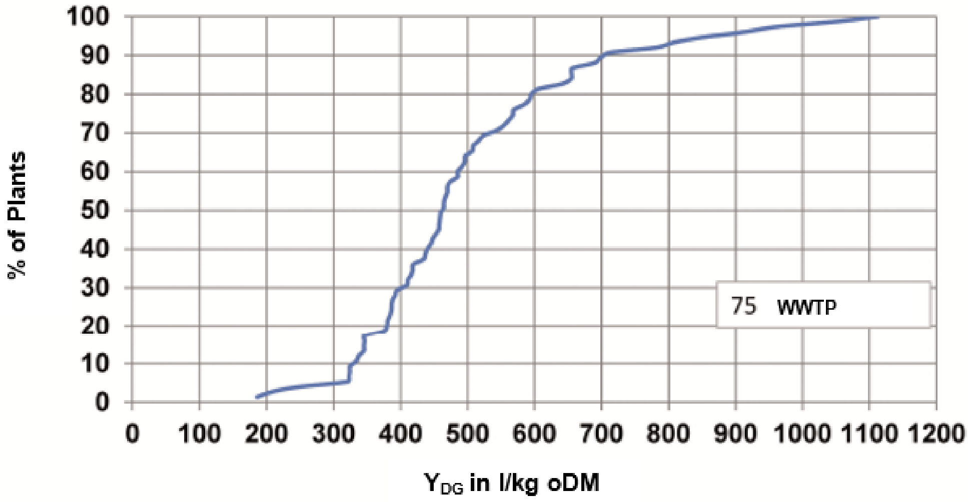


Figure 3.1.5. Specific digester gas yield Y_{DG} in relation to the organic dry matter fed [9]

According to Figure 3.1.6, the value for N_{DG} is only approx. 26% for 50% of the plants. It must be taken into account that the achievable values for N_{DG} are lower at smaller plants compared to wastewater treatment plants in size class 5.

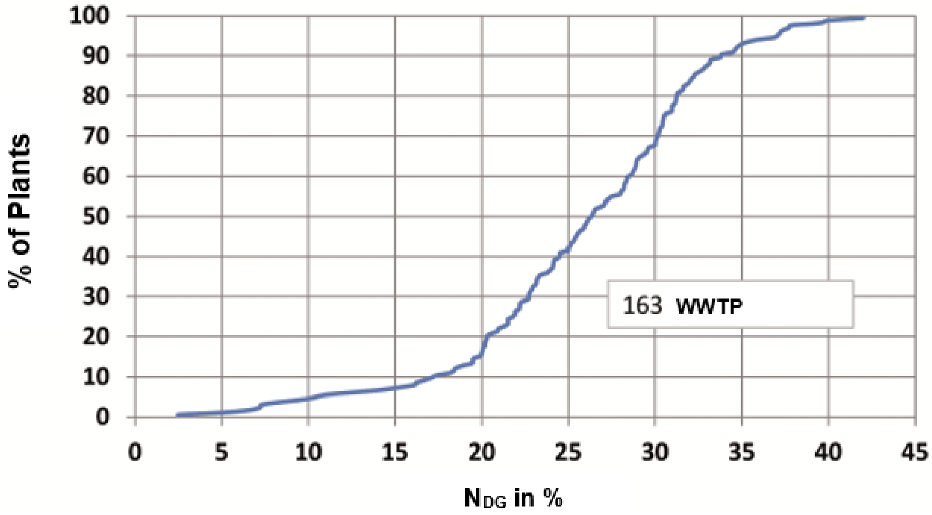


Figure 3.1.6: Degree of digester gas conversion to electricity N_{DG} [9]

The background to the parameter self-sufficiency in electricity EVel (%) in relation to digester gas electricity generation is the goal of complete utilisation of the digester gas quantity available at the wastewater treatment plant to largely cover the plant's own needs. According to Figure 3.1.7, in the 50% percentile, a self-sufficiency EV_{el} related to digester gas generation of 44% is achieved across all wastewater treatment plants considered.

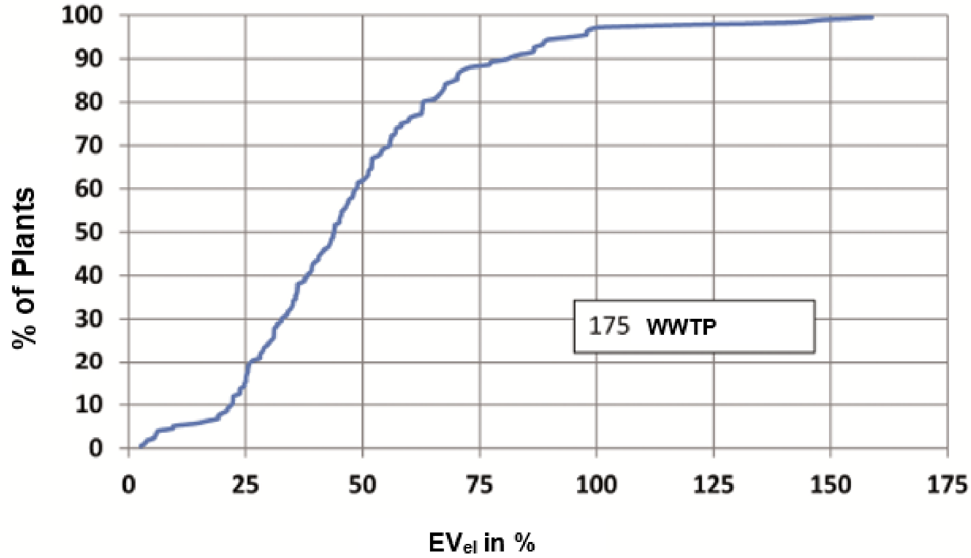


Figure 3.1.7: Degree of self-sufficiency with electrical energy EV_{el} [9]

The specific external heat requirement $e_{th,ext}$ provides information on the additional use of primary energy sources such as heating oil and natural gas to cover the heat demand at plants with sludge digestion. In the case of the use of purchased fossil primary energy sources in CHP plants, the energy quantities must be subtracted from $e_{th,ext}$ in the calculation. Figure 3.1.8 illustrates, that about 1/3 of all plants use additional fossil energy sources despite sludge digestion and digester gas production, which indicates a need for optimisation in principle. Wastewater treatment plants with sludge digestion should cover the heat demand completely via the CHP plant or other non-fossil heat sources. For plants where the heat demand is also covered by electrical energy, this parameter should be evaluated in conjunction with the specific total electricity consumption.

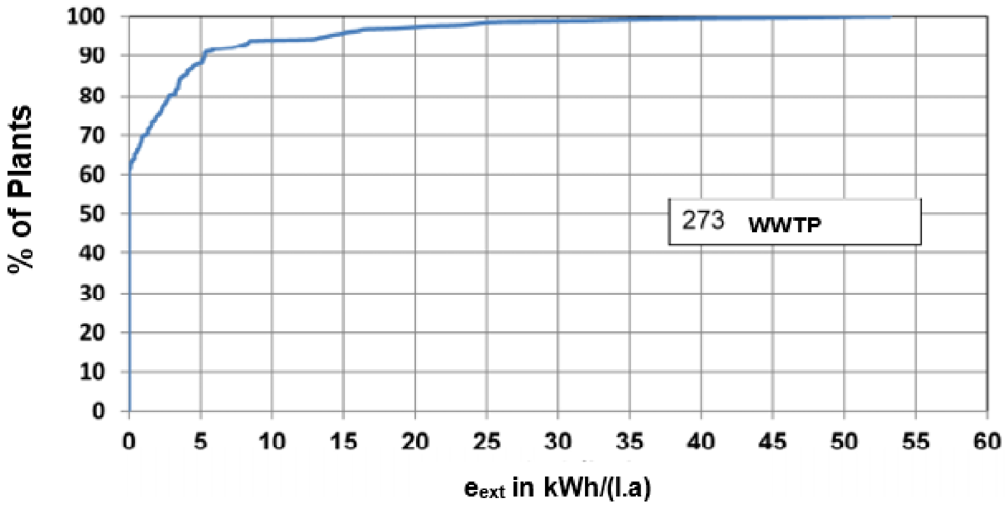


Figure 3.1.8. Specific external heat consumption e_{ext} [9]

The electricity consumption of pumping stations is often precisely recorded, as they usually have their own electricity meter. The actual flow rate and the manometric head are recorded less frequently. In order to come closer to the goal of a holistic view, key figures should also be determined for pumping station operation. The key figure electricity consumption per cubic metre of pumped wastewater provides important information for the energy evaluation of the pumping station. The first signs of wear and tear can be determined by means of a corresponding time series. It makes sense to differentiate between the three main classes of pumping stations - sewage, combined sewage and stormwater pumping stations; due to the current data situation, a corresponding differentiation is not yet possible. If information is available on the manometric head and the actual flow rate of the respective pumping station, the specific electricity consumption in Wh/(m^3.m) can be calculated from this. (Figure 3.1.9).

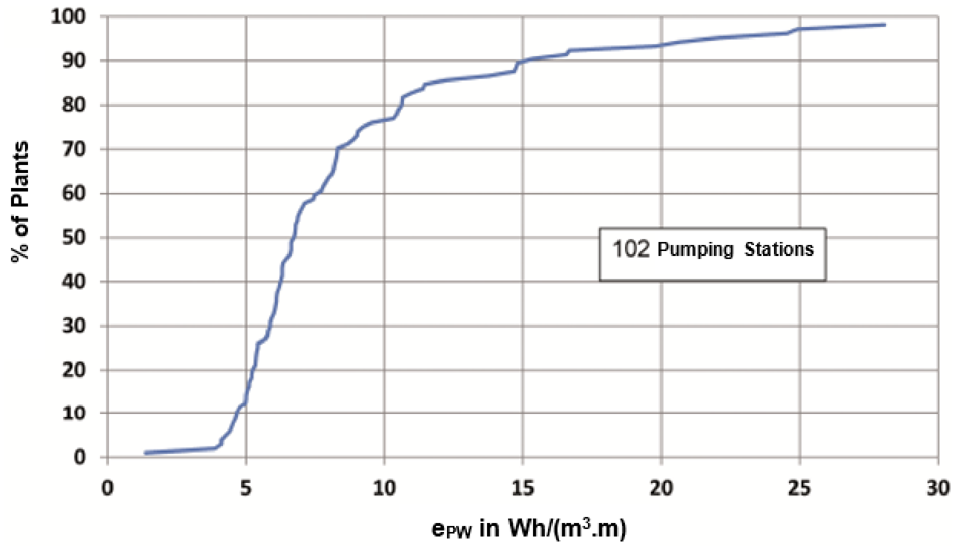


Figure 3.1.9. Specific electricity consumption of wastewater pumping stations e_{PW} [9]

3.2 Energy analysis

A detailed survey and evaluation of the energy situation of a wastewater treatment plant is an essential part of an energy analysis. The energy analysis examines the energy situation with regard to electricity and heat, comparing the consumption values with the reference and generation values. Heat is important, among other things, if wastewater plants purchase large amounts of external energy to cover their heat demand or if there are larger consumers nearby for the utilisation of surplus heat. The energy analysis shall develop optimisation measures, including a comparison of the cost framework with saved energy and operating costs.

It is appropriate if individual characteristic values in the energy check show potential for optimisation or are subject to a negative development over time. Even in the case of systems where the energy check shows characteristic values in the favourable range, the energy analysis can provide indications of optimisation potential. In the case of planned extensions or renewals of the wastewater treatment plant, the energy analysis supports the targeted development of measures. As part of the detailed energy analysis, it makes sense to define and determine a characteristic value in addition to the EV_{el} self-sufficiency level, taking into account other renewable energy sources such as wind energy, hydropower, photovoltaic systems, etc. The energy analysis consists of the steps shown in Figure 3.2.1, where steps 3 to 5 influence each other through their results and are to be processed iteratively. A more detailed description of the steps of the energy analysis flow chart is provided below.

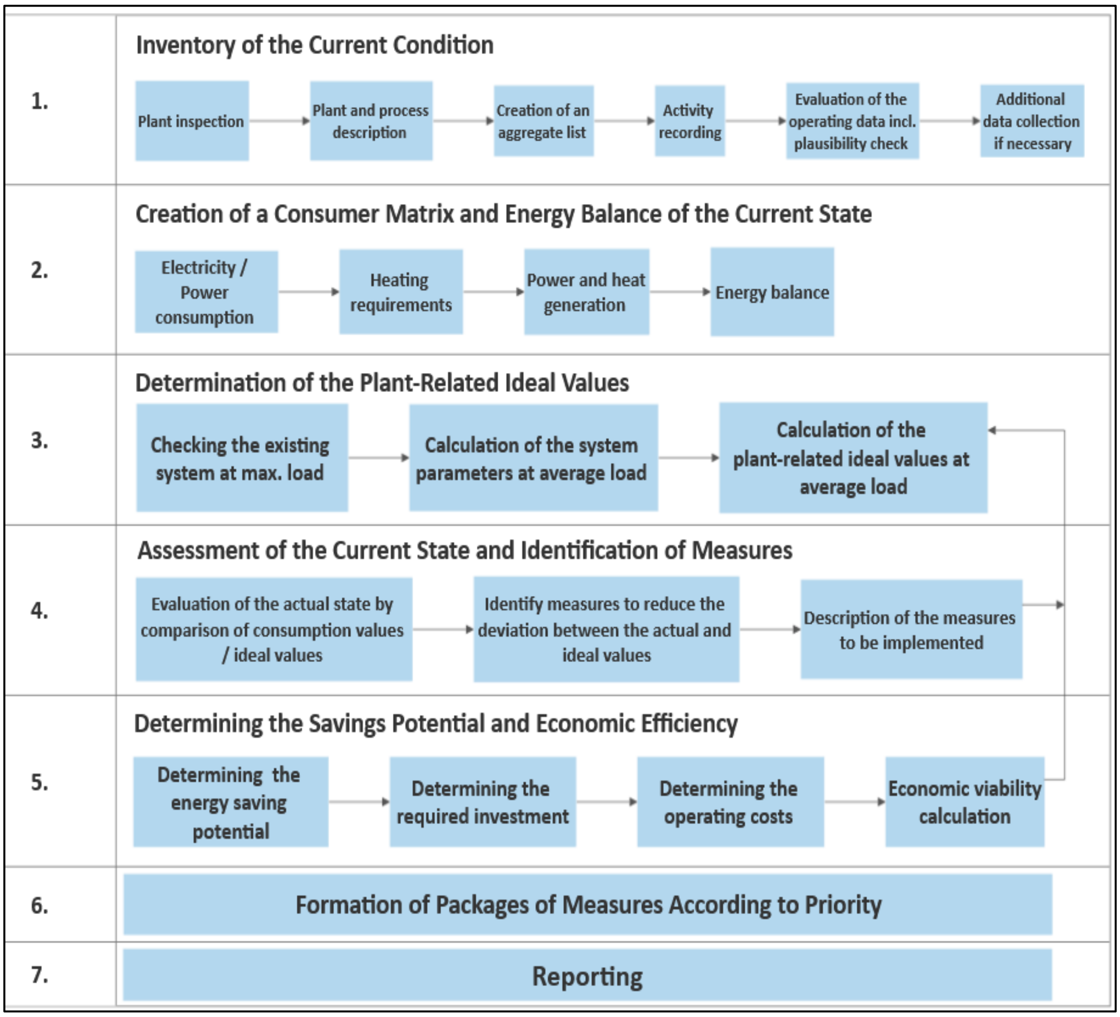


Figure 3.2.1. Flow chart of an energy analysis

3.2.1 Inventory of the actual condition

First of all, a condition survey is carried out as part of a plant inspection with the operating staff, in which deviations of the actual operation from the documentation documents (design/implementation documents, process diagram, etc.), but in particular procedural and energetic weak points or energetic potentials are determined according to the assessment of the staff on site.

The mode of operation of the plant as well as any special features are to be described and illustrated on the basis of flow diagrams for the wastewater and sludge path. The inventory of an energy analysis includes:

- results of the energy check and other available studies (e.g., process benchmarking),
- plant inspections,
- plant and process description,
- compilation of a list of aggregates,
- performance measurement of essential aggregates,
- evaluation of operating data incl. plausibility check,
- if necessary, determination of additional data collection.

The facility should be described with the information relevant for the energy analyses. In addition to the general object data, such as location address, contact persons and year of construction/expansion/refurbishment, the descriptive characteristic data must be compiled for each plant section or for each larger unit, and the operating data of the plant must be recorded. A plausibility check shall be carried out on the plant and operating data obtained.

These are to be listed in a list of aggregates with the corresponding performance data. If there is a lack of performance data, especially for larger machines or units with frequency converters, separate performance measurements must be carried out. In the event of an insufficient test result or insufficient scope of data, additional data surveys may be required.

3.2.2 Creation of a consumer matrix and energy balance of the actual state

Determining the electricity consumption

The most accurate possible determination of the active electrical energy of the individual consumers (also referred to in the following as electricity consumption) and of the treatment plant as a whole is of essential importance for the informative value of the informative value of the characteristic values to be calculated and for monitoring success. When recording the measured values, it must be ensured that suitable measuring instruments are used. This applies especially to units that generate harmonics, e.g., frequency converters or electronic dimmers.

Power grids are increasingly burdened by harmonics due to the growing number of electronic components. Due to these harmonics current flows in the neutral conductor even in symmetrically loaded three-phase networks and simple measuring devices for current measurement are no longer suitable (those which cannot compensate for harmonics).

The electrical active work W_{el} is generally determined in the three-phase system as the integral of the electrical active power P_{el} over time according to the following physical equations:

$$P_{el(t)} = \sqrt{3 \times I(t) \times U(t) \times cos\varphi(t)} \quad (3.1)$$

$$W_{el(t)} = \int_0^t \sqrt{3 \times I(t) \times U(t) \times cos\varphi(t)} \quad (3.2)$$

where, $P_{el(t)}$ is electrical active power
$W_{el(t)}$ is electrical active work

U is voltage in volt
I(t) is currently flowing through the circuit in ampers (A)
t is operating time period in h/a or in hours of the period under consideration

Any reactive power that occurs must be limited to a specified level within the system (reactive current compensation). For a rough calculation of the electrical active energy, average values of the voltage and current as well as the phase angle in the period under consideration can be assumed.

$$E_{el} = W_{el} = (U \times I \times \sqrt{3} \times cos\varphi) \times t \qquad (3.3)$$

where, E_{el}, W_{el} is electrical active energy
U is voltage in volts
I is currently flowing through the circuit in ampers (A)
t is operating time period in h/a or in hours of the period under consideration

Furthermore, it is decisive at which point the measurements are made, as each unit between the mains supply and the drive motor produces a voltage drop and thus losses. In general, the following chain is assumed, in which the aforementioned losses are to be expected in the following order of magnitude [9]:

- medium-voltage system < 0.1%
- transformer ~ 0.5%
- cable to switchgear ~ 1%
- switchgear and control system ~ 1%
- frequency converter (FU) ~ 5%
- cable to drive motor ~1% to 2%

The determination of the energy consumption of a unit is thus made up of its energy consumption plus the losses mentioned above. It is recommended that the measuring measurement technology to be installed as close as possible to the gensets to be monitored or the energy centre of gravity. The losses due to cables and frequency converters can be assigned to the respective aggregate or taken into account as a summary item in the energy balance. In practice, the consumption values of the gensets including upstream frequency converters are often available, so that corresponding losses do not apply.

At the time of the power measurement, the operating parameters of the respective unit that are decisive for the consumption must be documented, e.g., pump sump level or manometric head, pressure difference for blowers, delivery rate at the time of the measurement, etc. In the case of units that are subject to strongly changing diurnal cycles or seasonal fluctuations (e.g., inlet pumping station), an estimation of the current demand via a characteristic curve or map to be measured (e.g., current consumption as a function of the pumped water volume) in connection with operating data can also be useful if no current measurement is available.

An automated, permanent, and continuous recording of the electricity consumption for the most important aggregates and drives is recommended for the accuracy and efficiency of the energy inventory as well as for the success control of the measures taken. All plant aggregates must be listed in a consumer matrix according to process stages/plant groups. If consumption meters are available for plant groups or even aggregates, the values measured with them are to be checked for plausibility with the extrapolated values of the associated individual consumers.

Heat demand

For the wastewater system, the individual consumers are to be listed separately and the heat demand determined. If there are no heat quantity measurements available, the individual consumers can be estimated in accordance with the approaches in Annex

A.2 of the DWA A- 216. These values shall be calculated as a yearly average and, if possible, separately for the seasons. In particular, the following should be taken into account:

- transmission losses of the digester,
- heat demand for raw sludge heating,
- heating of buildings and hot water preparation,
- heat transfer to external heating networks,
- special applications such as process water heating (e.g., for deammonification),
- heat dissipation via the CHP emergency cooling system.

If the sludge is also thermally treated, the transmission losses and, if applicable, the evaporation performance of these processes must also be taken into account.

Power and heat generation

In addition to saving energy and increasing energy efficiency, the energy optimisation of wastewater treatment plants also focuses on energy generation. The potentials for this are in the sludge treatment, digester gas utilisation or the use of heat (from wastewater, waste heat from blowers, etc.) and hydropower. For the utilisation of the energetic potential of heat from wastewater is set out to the Code of Practice DWA-M 114 "Energy from wastewater - heat and positional energy", which provides detailed technical information on this topic.

In principle, it is possible to generate one's own electricity at sewage treatment plants via CHP plants (digester gas or natural gas CHP), PV plants, wind energy plants, small hydroelectric power plants, etc. For further balancing, the total net electricity generation as well as the shares for self-supply and for feeding back into the public electricity grid must be documented.

The degree of self-sufficiency is determined as part of the energy analysis. The degree of self-sufficiency refers exclusively to the "energy from wastewater", i.e., usually from biogas, which is obtained directly from sewage sludge or from the wastewater flow (e.g., in the case of industrial wastewater plants) and converted into electricity and/or heat. Within the scope of the energy analysis, co-digestion is classified as wastewater-borne energy. Electricity from PV plants, wind energy plants and small hydropower plants etc. is to be excluded. This also applies to own electricity generation from fossil energy sources. If units are directly driven by biogas/natural gas engines, etc., their power shares must be calculated as electrical power equivalents and also included in the degree of self-sufficiency (biogas) or external procurement (natural gas CHP).

The amount of heat generated is to be read via the existing heat meters of the individual aggregates such as burners or CHP units. If no heat meters are installed, the amount of heat generated can be determined via the primary energy quantities used on the basis of the manufacturer's specifications for thermal efficiencies. For correct balancing of the gas quantities, their recording in standard cubic metres [m³ i. N.] and the determination of the calorific value is essential.

Electricity shares used for electric heating or for electric heat pumps must be accounted for in the energy balance in electricity consumption as energy for heat generation. The amount of heat generated in the process, including the waste heat used, is included in the heat balance on the generation side. The same also applies to the direct use of waste heat, e.g., in sludge-sludge heat exchangers.

Energy balance

The sum of the electricity demand of all aggregates including losses must be shown in the balance sheet, taking into account measurement tolerances in the recording of electrical and physical parameters. The sum of the electricity demand of all units, including losses, must correspond to the actual electricity consumption (utility bill) plus the net electricity generation minus feed-in.

Similarly, the heat demand determined, including heat discharge into external networks and targeted heat dissipation via emergency coolers is compared to the heat generation (closed heat balance). This can be presented in tabular form as in Annex E of the DWA A- 216 or in the form of Sankey diagrams. The latter allow the representation of the energy flows of all energy sources in a closed diagram (Appendix F of the DWA A-216).

3.2.3 Determination of the plant related ideal values

Preliminary remark

The plant-related ideal value of a wastewater treatment plant is composed of the plant-related ideal values of the individual process engineering units. The individual plant-related ideal values are not fixed values but depend on the boundary conditions of the existing plant configuration and mode of operation. For the defined boundary conditions, the respective optimal energy demand is determined for the individual process units and compared to the existing energy demand. Appendix A of the DWA A-216 provides assistance in selecting optimal value ranges.

The comparison of the plant-related ideal values with the values of the actual state results in savings potentials and approaches for the development of measures. By varying the boundary conditions within the scope of the energy analysis, the determination of plant-related ideal values for different scenarios offers the possibility to also evaluate serious and long-term developments with regard to energy demand.

Review of the existing plant

At the beginning, the required volumes and aggregate sizes of the wastewater system are to be checked. With regard to the municipal wastewater treatment plant, the necessary tank volumes of at least the grit chamber, primary sedimentation and biological stage as well as the required material flows for any pumping stations, aeration facilities and sludge treatment aggregates are to be determined for the relevant load, taking into account load increases. The various worksheets/leaflets of the DWA, in particular the worksheets ATV-DVWK-A 198, DWA-A 131:6/2016 and the leaflets DWA-M 229-1 and DWA-M 368, provide assistance for the calculation of the system.

Calculation of the system characteristic values for average loads

The basis of the plant-related ideal values are annual mean values. Accordingly, the material flows for pumping stations, aeration equipment and sludge treatment aggregates are to be determined at the average annual load. The recalculation of an activated sludge plant thus yields the annual average oxygen demand, sludge production and sludge age on the basis of the existing tank volumes, the average dry matter content set during operation and the average temperature. The recalculation is usually carried out according to the DWA-A 131:6/2016. For this calculation of the activated sludge plant are to be based on:

- annual mean loads in the influent of the activated sludge plant, taking into account the backloads (process water, etc.),
- mean annual volume flows of the internal circuits (internal recirculation, return sludge),
- mean solids concentration and mean annual wastewater temperature.

The results of the recalculation shall be compared with the real operating data. If significant deviations occur in sludge production, dry matter content, recirculation volume or return sludge volume, the operating data used and the calculation assumptions incorporated shall be reviewed.

Calculation of the plant-specific ideal values

To determine the plant-specific ideal value of individual Aggregates or Aggregate groups, the specific ideal values of the optimal electricity demand given in Appendix A.1 of DWA A-216 (column "Optimal values and value ranges") are used in conjunction with existing operating parameters. By using the operating variables (e.g., influent water quantity, influent load) in the calculation, an ideal expected electricity demand (kWh/a or kWh/(I.a)) is determined for each plant section, which can be directly compared with the actual figures (DWA A-216 Appendix C). If it is not possible to determine the plant-specific ideal values by multiplying the specific ideal values by operating values, the values in the table in DWA A-216 Appendix A can be used as an alternative. In DWA A-216 Appendix A, the calculation approaches of the usual process technologies of municipal wastewater treatment plants are compiled. Specific ideal values from other sources of process technologies, which are not listed in this appendix can be applied using the same methodology.

Boundary conditions that cannot be changed or can only be changed with considerable effort, such as geodetic heights, wastewater quality or wastewater quantity, must be taken into account according to the actual conditions. The calculated plant-related ideal values are arranged according to process engineering units, compared with the actual electricity and heat demand and the electricity and heat generation. As a rule, the absolute values are to be presented in kWh/a and the specific values in kWh/(I.a).

The plant-related ideal value of the heat demand of a wastewater facility is ideally calculated as an annual hydrograph according to the formulas in DWA A-216 Appendix A.2, separated into summer and winter half-years. The plant-related ideal values for electricity and heat generation result from the calculation approaches given in DWA A-216 Appendix A.3, using the specific ideal values for combined heat and power plants (CHP, micro gas turbine).

3.2.4 Assessment of the current state and identification of measures

Assessment of the actual state

For the assessment, the values of the actual condition are compared with the plant-related ideal values. For this purpose, actual values and plant-related ideal values are classified by sub-units according to DWA A-216 Appendix A.1. From the difference, a savings potential can be identified for the respective aggregates or process groups.

Identification of measures

To identify measures, the causes for the differences determined in the above-mentioned assessment must be worked out. Possible starting points are:

- adjustment of operating parameters,
- use of energy-efficient aggregates,
- use of optimally dimensioned units,
- adaptation of process technology.

Replacement procurement (energy-efficient drives, aeration elements) is a good opportunity to develop measures. In the area of constantly operated aggregates (agitators, return sludge transport, internal recirculation, etc.) or controlled operating settings (e.g., oxygen content, level in the pump sump, dry substance content, etc.), it is necessary to check variables set during plant operation. For this purpose, the actual operating values must be compared with the calculated operating values.

The measures to be derived require consideration in the overall context, i.e., taking into account the requirements to be met (process requirements, process engineering procedures, safety aspects, etc.). Since EI&C technology is closely linked to machine and process technology, the electrical engineering measures must be developed in close relation to the optimisation of the process technology. In a first step, the respective process engineering component should be checked before the electrotechnical optimisation takes place.

For optimisation in the area of heat, the large-scale consumers such as anaerobic sewage sludge stabilisation, building heating and, if applicable, thermal sludge drying are primarily decisive. Due to the high share of raw sludge heating in the total heat demand of the wastewater treatment plant, the degree of pre-thickening should be checked.

Energy optimisation on the generation side extends especially to digester gas utilisation (electricity and heat) and heat recovery (e.g., from digested sludge, wastewater, compressed air, etc.). When considering the energy optimisation of wastewater treatment plants, it could be worthwhile to include process changes in the considerations, especially if crucial plant components have to be renewed and/or the wastewater composition has changed significantly compared to the original planning status.

In order to describe the measures, the influence on plant operation must be described in addition to the process technology. For example, the effects on operational management and, if applicable, on sludge treatment and effluent quality of the plant.

3.2.5 Determining the savings potential and the economic efficiency of the measures

Determining the energy savings potential

The energy saving potential of the identified measures is calculated from the difference between the energy use of the actual state and after implementation of the identified measures. For this purpose, the developed measure must be incorporated into the calculation carried out, for example by applying the improved efficiency of the new pump or optimised operation when replacing a pump. The approaches according to the tables in DWA A-216 Appendices A.1 to A.8 are therefore also an analysis tool with which not only the actual state can be evaluated but also the effects of optimisation measures can be calculated.

Determining the economic efficiency

To assess the economic efficiency of the measure, the costs of the measure (debt service of the investment, changed operating costs) must be compared with the savings (energy costs, reduction of operating materials, wastewater levy, etc.). The necessary investments are to be listed for the construction, mechanical and electrical engineering. Subsidies, grants, and revenues or other legal benefits can be taken into account and must be shown separately.

It should be noted that, due to the planning depth of an energy analysis, the cost calculation carried out corresponds to the determination of a cost framework in accordance with DIN 276-1. More detailed cost calculations and in-depth economic feasibility studies are the subject of more extensive planning (HOAI planning services).

The energy demand of aggregates often increases with the operating time. Particularly with respect to replacement of aeration elements in the aeration tank, the energy savings that can be observed initially decrease after replacement. This must be considered when assessing the economic efficiency.

The simplified procedure can be used to estimate the economic efficiency, taking into account the prerequisites of the KVR guideline (DWA 2012). Here, the additional annual costs and operating costs caused by the optimisation measure are put in relation to the savings. A cost-benefit ratio of less than 1 indicates economic feasibility.

A sensitivity analysis is useful to validate the results from the cost comparison calculation. Important influencing factors are, for e.g., the fluctuation range of investment costs, interest rate or energy price fluctuations.

3.2.6 Formation of packages of measures according to priority

The identified measures are divided into immediate measures, short-term measures, and dependent measures.

Immediate measures (I) are optimisations that can be implemented within a short period of time with limited effort. Criteria for this are good cost-benefit ratio, little planning effort, independence and simple implementation. Typical examples are changes to aggregate switching points or setpoint specifications.

Short-term measures (S) can be realised within a short time as part of an energy refurbishment/extension. They may require more detailed investigations as part of a planning as well as supplementary measurements. Typical examples are significant changes in the programmable logic controller (PLC) or replacement of individual units or unit parts.

Dependent measures (D) can, due to the frequently unfavourable cost-benefit ratio, be implemented economically only in conjunction with larger repair projects, conversions and replacements. In this context, medium-term price or cost developments should be taken into account, which may make initially uneconomical measures economically interesting in the medium term due to technical and economic developments. Examples of dependent measures are: Fundamental process conversion, replacement of defective aggregates, CHP construction in the course of the construction of a digestion plant, etc.

The measures are to be grouped into packages according to the implementation phases (I), (S) and (D) and listed in the form of an energy certificate (DWA A-216 Appendix G) with regard to the predicted savings effects. The measures to be realised economically are to be listed with information on the time of realisation, the cost-benefit ratio and the savings effects.

3.2.7 Reporting

The results of an energy analysis are documented in a report. The structure of the report is based on the work steps of the energy analysis. The report shall include at least the following contents:

- introduction, content and objectives,
- presentation of the results of the inventory and the energy check, description of the process plant based on a process diagram, list of aggregates with their energy parameters, energy balance for electricity and heat based on the list of aggregates,
- determination of the plant-related ideal values, comparison of the actual and plant-related ideal values to identify measures,
- development of measures based on the individual optimisation potentials, including description of measures and profitability analysis (the profitability analysis is to be presented uniformly for each measure according to the same scheme), summary presentation of the identified measures in a table corresponding to the realisation phases (saving potential in kWh/a, €/a; the expenditure in €, €/a; cost-benefit ratio),

- proposals for monitoring success,
- summary and outlook for further action.

3.3 Performance comparison of municipal wastewater treatment plants DWA

For more than 25 years, the German Association for Water, Wastewater and Waste (DWA) has been monitoring the development of German wastewater treatment plants. The DWA performance comparison shows the quality of wastewater treatment and the electricity consumption spent on it, and also the sludge production. The performance comparison provides a comprehensive picture of the improvement of effluent values and degradation levels over three decades.

Performance comparison has been continuously developed and today it includes the relevant influent and effluent values (BOD_5, COD, NH_4, total nitrogen and total phosphorus), degradation rates and electricity consumption. Depending on the regional characteristics of the various DWA regional associations, other parameters are also collected, e.g. extraneous water and wastewater volumes. Most recently, the parameters electricity generation and digester gas generation have been added nationwide.

With changing focal points, the focus was on e.g., nutrient removal, the performance of the different purification processes and electricity consumption. In future, too, current developments are to be taken up in order to provide further impulses for optimal operation. Further increases in treatment performance are possible through the use of more advanced wastewater treatment processes (e.g., filtration, addition of activated carbon or ozone). In this context, the annual performance comparison could also be used to carry out the energy check for the sewage treatment plants.

Project "Wastewater Treatment Plant Performance Comparison" is not yet complete and it must be continuously adapted and further developed to new issues in the wastewater sector. This makes the performance comparison a valuable database that documents the status and development of wastewater treatment in a clear and comprehensible way.

4 Technologies to reduce GHG emissions

4.1 Indirect GHG emissions (energy optimization)

4.1.1 Anaerobic vs aerobic digested sludge stabilization

Aerobic process

Aerobic processes can be performed in several ways. In the simultaneous aerobic sludge stabilisation in aeration tanks for aerobic wastewater treatment, a large number of different microorganisms are involved, which develop depending on the respective load condition. Advantages are the high level of operational safety due to the buffer capacity and the low operating and monitoring effort. Compared to separately aerobically or anaerobically stabilised sludges, the dewaterability of simultaneously aerobically stabilised sludges is significantly worse (not sufficiently stabilised due to the process). [10]

In separate aerobic sludge stabilisation, the process speed also depends on the temperature in the reactor (increasing temperature from the psychrophilic to the mesophilic to the thermophilic range the species diversity of the active biocoenosis decreases in extreme cases to the point of monoculture). Above a temperature of approx. 40°C, hydrolysis becomes only moderately faster, if at all. In the temperature range below 35°C, with sufficient oxygen supply, it can be assumed that degradation is the same for joint and separate aerobic stabilisation. Above 35°C and into the thermophilic range, the sludge age for separate aerobic stabilisation must be at least five days, according to various studies of large-scale plants, in order to stabilise the sludge just as conditionally as for joint aerobic stabilisation at temperatures up to 35°C. Compared to aerobic-thermophilic stabilisation, separate and unheated aerobic stabilisation is less efficient. [10]

Anaerobic process

Sludge digestion is based on the symbiotic activity of different types of bacteria, which break down high-molecular organic matter into smaller fragments, and of methane bacteria, which essentially convert these fragments into methane and water. Later, special acid-producing bacteria were isolated. Recently, at least four types of bacteria have been distinguished, which carry out the following degradation steps: hydrolysis, acidification, acetate and methane formation. [10]

A variety of practical experiences at different digestion plants have shown that the alleged temperature optima of the anaerobic biocoenoses do not have to be adhered to in practical operation, but that the temperature of digesters can be adapted to the heat balance of the overall system of the sewage treatment plant if this is done slowly. Excess heat generated in summer can be used to increase the temperature in the digester and in winter digesters can be operated somewhat cooler. [10]

For commonly composed municipal wastewater, it can be assumed that about 70% of the organic solids in the primary sludge and about 45% in the surplus sludge of an activated sludge plant with nitrogen elimination are easily biodegradable. For municipal raw sludge of common composition, it can be roughly estimated that the degradation-specific gas production from the organic substances of the primary sludge is approx. 0.95 m^3 i.N./kg and surplus sludge approx. 0.85 m^3 i.N./kg. The greatest substrate for degradation-spetcific digester gas generation is organic fat, then carbonhydrates and protein. In terms of energy content (MJ/kg), the sequence are organic fats, proteins and carbonhydrates. The gas yield can be increased considerably by adding co-substrates, what must be sufficiently pre-treated before they are fed to the digester directly or after mixing with the raw sludge. [10]

Table 4.1.1. Sludge stabilization process [10]

Treatment	Milieu	Consistency	Heat supply	Process	WWTP size class	Remarks
Biological	Aerobic	Fluid	Without effective self-heating	Simultaneous aerobic stabilisation	Small to medium	Conditionally stabilised
		Thickened	Self-heating	Aerobic-thermophilic sludge stabilisation (liquid composting)	Small to medium	Disinfection attainable at the same time
		Dewatered	Self-heating	Composting in windrows or bioreactors	Small to medium	Disinfection attainable at the same time
	Anaerobic	Thickened	Without heat input/ supply	Emscher basins, unheated digesters or anaerobic ponds	Small	No longer used in Germany
			With heat input/ supply	Heated digesters	Small to large	Disinfection achievable with thermophilic operation
		Dewatered	With heat input/ supply	In gas-tight containers	Small to medium	Not yet used for sewage sludge
	Dual	Thickened	With heat supply and recovery	Mostly aerobic-thermophilic and anaerobic-mesophilic	Medium to large	Disinfection attainable at the same time
Chemical	Aerobic or anaerobic	Thickened	Without self-heating	Addition of lime	Small	Only pseudo stabilisation, disinfection attainable at the same time
		Dewatered	With self-heating	Addition of quicklime	Small	
	Aerobic	Thickened	With heat input/ supply	Wet oxidation	Large	Disinfection at the same time
Thermal	Aerobic	Dewatered	With heat input/ supply	Drying	Small to large	Only pseudo stabilisation, disinfection attainable at the same time

4.1.2 Anaerobic pre-treatment of industrial wastewater (reduction aeration energy and biogas production

The technology of anaerobic municipal wastewater treatment does not differ in the essential basic points from industrial wastewater treatment. In both cases, biogas is produced via anaerobic degradation and, due to the low excess sludge production, sufficient retention of the active biomass in the system must be ensured. The most commonly used reactor type in anaerobic municipal wastewater treatment is the upflow Anaerobic Sludge Blanket (UASB) reactor. [1]

In addition to the substances transported by the wastewater, an anaerobic reactor also emits gases (mainly methane, carbon dioxide and hydrogen sulphide). The energy content of the gas is determined by the proportion of methane it contains. The main advantages of anaerobic industrial wastewater treatment over conventional aerobic treatment are [1]:

- comparatively small tank volumes, because reactors are operated at very high COD loads up to 30 kg COD/(m^3.d) (usually high reactors, less area, which mean small footprint),

- the surplus sludge produced is already largely thickened and well stabilised due to the high sludge age,
- the specific excess sludge production is approx. 0.15 kg oTS/kg COD for the acidifying anaerobes and approx. 0.03 kg oTS/kg COD for the methanogenic archaea. COD, so that, depending on the degree of acidification and the proportion of undissolved inert matter is 3-10 times lower than in aerobic processes,
- dosage of nutrients and trace elements required is lower,
- some substances that are difficult or impossible to degrade aerobically can be degraded anaerobically (e.g. pectin, EDTA, reactive dyes, higher chlorinated aliphatics, aromatics and substituted aromatics),
- the energy demand of anaerobic processes is comparatively low (not necessary cost-intensive aeration),
- the methane content of the generated biogas is between approx. 60 and 80%, calorific value of approx. 6-8 kWh/m^3 and it can be used thermally and/or electrically,
- odour emissions are very low when operated properly (reactors are completely covered),
- the wastewater treatment costs are generally significantly lower (low construction volumes, small amount of excess sludge, low energy demand and the energy gain),
- anaerobic processes are particularly suitable for seasonally operations (anaerobic biomass is active again within a few days).

4.1.3 Deammonification (reduction C and aeration demand)

Deammonification is a process in which two nitrogen removal processes take place simultaneously or alternately in one process unit - nitration and anammox. Various studies have been carried out within the projects, the results of one project are described below. The aim of the project “Energy self-sufficient wastewater treatment plant with deammonification” was to reduce electricity consumption, increase digester gas production and thus increase the efficiency of the plant. In addition to these goals the amount of sewage sludge was to be reduced. During the project the process of wastewater treatment and treatment sludge water changed to EssDE® (combination of A-B process with deammonification). In the case of deammonification, a distinction must be made between deammonification in the side stream for the process water and deammonification in the main stream, which has not yet been implemented on a large scale in Germany. [11]

Two different processes (deammonification in the disc immersion tank and Demon+®) were used for the treatment. In the projects, it was not possible to balance the electricity savings based only on the partial flow treatment, so that it is also not possible to make an economic assessment of only this process in terms of electricity savings. The economic efficiency seems to come more from a reduction in the load on the activation and thus a higher reserve capacity, but this is also difficult to quantify. The currently common deammonification with the activated sludge process requires very careful monitoring as well as strict compliance with certain boundary conditions (feed low in solids, constant temperatures, regular maintenance of the sensor system, good control of the aeration cycles, etc.). In the summary of the project, the implementation of the measures has significantly reduced the specific total electricity consumption, but the target value could not be reached. In principle, the following applies to deammonification [11]:

- the savings potential is difficult to balance, because savings in aeration in the mainstream are partly compensated by additional electricity consumption for partial stream treatment,
- the commissioning phase is also difficult with conventional SBR plants for deammonification difficult and strongly dependent on constant wastewater temperatures. Qualified and motivated operating staff is required, which makes it difficult to use in developing countries.
- In Germany, the implementation potential lies mainly in off-stream treatment and there mainly in plants that have an unfavourable N/CSB ratio in the influent.

Overall there is still a great need for research on the implementation opportunities and the effects of this process on the energy efficiency of wastewater treatment plants, not least under the aspect of possible additional emissions of highly climate-damaging nitrous oxide in this process step. The savings potential through deammonification in the side stream is difficult to quantify and is likely to be of particular interest for wastewater treatment plants that have a high N/CSB ratio in the influent. [11]

4.1.4 Co-digestion (increase of digester gas yield)

Anaerobic digestation is carried out with the primary and excess sludge from biological wastewater treatment, to which organic residues (co-ferments) are introduced. In the digester, the sludge is largely converted into digester gas. The anaerobic sludge stabilisation is followed by sludge dewatering, during which the dry matter content is increased by a mechanical device, thus significantly reducing the volume of sewage sludge to be disposed of. [12]

To improve the quality of the centrate, a pressure screen will be implemented and operated in this stream in the future. Due to the low proportion of pre-screened organic residues (co-ferments), no deterioration in the effluent quality of the treatment plant is to be expected. In future, the dewatered sewage sludge will be fed into a thermal utilisation process (incineration). Co-digestion advantages [12]:

- increasing the sewage treatment plant's own electricity supply (public sector),
- reduction of specific CO_2 emissions,
- further energetic utilisation of the digested sludge (thermal utilisation/incineration)
- increasing the solids content in sewage sludge dewatering due to the lower water-binding capacity of biological waste compared to municipal sewage sludge;
- minimising the risk of contaminants (e.g. plastics) being discharged into the environment through targeted separation in the wastewater treatment process.

4.1.5 Heat recovery from wastewater (sewer or WWTP inlet)

The heat contained in wastewater is a regenerative heat source. Although it is often at a moderate temperature level, it is always available in sufficient quantities at every wastewater treatment plant. With the help of a heat pump, the temperature level can be raised to an extent that can render this thermal energy useful for efficient and reliable low-temperature sludge drying. The recovery of heat from treated wastewater has the following advantages [13]:

- due to the large quantities of water, considerable heat potentials are also available,
- sewage treatment plants often have a large heat demand.

The recovered heat can be used, as explained above, to support sludge drying. Solar drying uses the free energy of solar radiation, but the sun does not always shine sufficiently strongly everywhere. In order to reduce the area required for solar drying in these cases and/or to maintain year-round operation, wastewater heat acts as a reliable regenerative heat source in addition to regenerative solar energy. [13]

4.1.6 Hydraulic energy recovery in the effluent WWTP (turbines)

Another way to harness power from WWTP effluents is in the forms of hydraulic energy. Where water flows sufficiently steep (downwards), turbines, Archimedean screws or water wheels can be installed to harness its energy and generate electricity. [13]

4.1.7 Solar sludge drying

The raw or digested sludge produced at sewage treatment plants should be additionally dried after dewatering for further utilisation. Solar sewage sludge drying has shown to be particularly promising in terms of treatment success and economic efficiency. A recycling-oriented sewage sludge management prefers a return of valuable substances contained in the sewage sludge into the material cycle to disposal. The concentrations of pollutants and pathogenic microorganisms in the treated sewage sludge should be reasonably low for this. [14]

Solar sewage sludge drying mainly uses global radiation as an energy source, so that primary energy consumption is reduced to a minimum. The dewatered sludge (in rare cases also wet sludge) is dried on a paved surface (usually made of concrete), which is enclosed with a transparent building shell, comparable to a conventional greenhouse from the agricultural industry. The short-wave global radiation enters the drying hall through the glass building envelope and is reflected on the floor as long-wave thermal radiation, which cannot leave the building envelope again. This greenhouse effect causes the indoor air to heat up. In order for the evaporation of the water and the drying of the sewage sludge to proceed optimally, the sludge must be well ventilated (regular exchange of air) and turned several times. In this way, a dry granulate with a dry residue of 90% can be produced. [14]

Solar sewage sludge drying is a further development of treatment in drying beds. In Germany, drying beds are no longer common, but this method is still a suitable variant for other regions. It is often used for the treatment of faecal sludge, e.g., from septic tanks and dewatering in small and medium-sized wastewater treatment plants (up to 20,000 inhabitants). Most of the water is extracted as seepage via the drainage, a smaller proportion evaporates. [14]

To avoid excessive odour pollution, the sewage sludge should be stabilised, or at least partially stabilised. To further avoid odour emissions, an exhaust air treatment system can be installed. However, even in this case, it must be ensured that staff are not exposed to harmful emissions (e.g., pathogenic germs, H_2S, NH_3). [14]

4.1.8 Desulfurization of digester gas by micro-aeration

The biogas produced from the anaerobic digestion of sewage sludge can contain H_2S concentrations and according to DWA M-361 typical H_2S concentrations in biogas are between 500 and 1,500 ppmv. In the anaerobic digester H_2S ends up in the liquid and gas phase. Desulphurisation is an important step in the biogas upgrading process. It is necessary to remove H_2S to prevent inhibition of methanogenic bacteria, odour and corrosion of the digester and excessive formation of SO_2 when the biogas is combusted. Currently, the removal of H_2S from biogas is largely carried out by biological and physico-chemical treatments (e.g., adsorption, membrane separation, stripping), what is very effective in archiving high H_2S removal rate, but often associated with high CAPEX and OPEX (require additional equipment and chemicals, some cases operation at high pressure, temperature). [15]

Biological H_2S removal method is microaerobic H_2S removal in the headspace of anaerobic digesters. Micro-aeration offers several advantages over conventional desulphurisation methods: increased biogas potential, oDM degradation and dewatering quality, lower CAPEX and OPEX. The reduced oDM load also leads to a reduction in disposal costs and transportation emissions for the dewatered sludge. Reducing the sulphide concentration in the liquid has the positive effect of reducing potential sulphide toxicity to methanogens. Most studies report no or negligible decrease in methane production due to micro-aeration. However, excessive sulphur build-up in the digester headspace can impair removal performance over time by reducing the residence time of the biogas and, accordingly, the oxygen transfer rate to the microorganisms. This requires regular cleaning to maintain H_2S removal efficiency. [15]

4.1.9 Optimization of aeration in aerobic treatment stages

The task of aeration systems is to introduce the oxygen required for the metabolism of aerobic microorganisms into the aeration tank. Pressurised aeration and surface aeration systems are used for this purpose. In the course of the energy optimisation, an overview of a possible replacement of the existing aerator elements is to be created (compare possible available aerators on the market). [16]

In pressurised aeration systems, oxygen transfer takes place through the air bubbles rising in the water. Only part of the oxygen contained is transferred to the water. Oxygen is transferred depends on various influencing factors: bubble size, turbulence in the phase boundary layer, residence time of the bubbles in the water, oxygen concentration in the aeration tank, temperature and wastewater constituents. The larger the interface between air and wastewater formed by the surface of the air bubbles, the greater the amount of oxygen transferred into the wastewater. The smaller the individual air bubbles, the larger the total surface area of the air bubbles. [16]

Surface aeration oxygen transfer occurs through the mechanical action of the aerators on the surface of the water (e.g., vertical axis centrifugal aerators and horizontal axis roller aerators). In addition to oxygen input, surface aerators also create a flow field, which mixes the activated sludge and the contents of the wastewater and prevents sludge build-up. With surface aerators, 90% to 100% of the pure water oxygen supply can be expected in wastewater. [16]

Mathematical modelling most focus is on the use of a tool to support design and dimensioning. Such models are based on so-called 0-dimensional approaches (stirred tank models) and offer the possibility to describe the processes in fully mixed reactor volumes and thus to make statements about the mode of operation and the efficiency of a wastewater treatment plant. The influence of the flow as well as spatial structures can only be taken into account in a simplified way. In contrast, multi-dimensional mathematical models - so-called CFD models - offer the possibility to spatially map a single basin and to obtain a comprehensive insight into the processes taking place. The performance of 3-dimensional flow simulations is used to support new planning, rehabilitation and optimisation. Typical issues investigated using a 3-dimensional simulation model [16]**:**

- mixing of the inflow flow into the basin,
- formation of short-circuit flows between inflow and outflow,

- formation of dead zones or areas of low near-bottom velocities, which can lead to permanent sedimentation,
- positioning of aerators/agitators,
- distribution of oxygen in the basin.

The performance of aeration systems is evaluated by the oxygen supply and the energy required for this. Essentially, the performance is influenced by the injection depth, the occupancy density, the air admission and the wastewater constituents (α-value). All other things being equal, greater injection depths also result in a higher oxygen supply SOTR compared to a shallower injection depth. The specific oxygen supply, on the other hand, decreases with increasing injection depth. [17]

Specific study on the optimization of technical and economical factors was carried out at a German communal WWTP in Wolfsburg to assess different types of aerators (different manufacturers). The comparison of the aeration elements has shown that the specific oxygen input standardised to the air volume per active aeration area is almost identical, but a clear difference can be seen with regard to the pressure loss (generally lower with disc diffusers than with tube/plate or strip diffusers). By optimising the arrangement of the aerators in the aeration basins, a significantly improved oxygen utilisation can be achieved with the strip and plate aerators. In terms of reducing operating costs, it is therefore recommended to select the highest possible occupancy density (regardless of the type of aerator) in order to generate a more fine-bubble air input with a lower air volume and thus achieve a higher utilisation rate. Furthermore, the overall system of blower and aerator in connection with the actual load of the aeration stage is of decisive importance for economic efficiency. Another factor is the control of the aeration. These factors were only considered superficially or not at all in this brief study. [17]

4.2 Direct GHG Emissions

4.2.1 Digester gas flare and CHP

The energy content of a biogas depends on its methane content. Under normal operating conditions, the CH_4 content for the various biogases lies within the ranges of variation compiled below and leads to the correspondingly assigned energy contents (calorific values) (Table 4.2.1). Co-treatment (co-fermentation) of agricultural, commercial, agro-industrial or municipal biogenic waste, together with a basic substrate such as sewage sludge or farm manure, influences both the specific biogas production and the biogas composition. The biogas yield from anaerobic industrial wastewater treatment depends on a number of other influencing factors such as: type of industrial operation, water consumption and specific pollution and type and operation of the anaerobic wastewater treatment plant. [18]

Table 4.2.1. Reference values for methane contents and calorific values of biogases [18]

Biogas	CH_4 content [Vol.-%]	Calorific value [kWh/m³]
Biogas from sewage sludge digestion plants	60 – 70	6,0 – 7,0
Biogas from the anaerobic treatment of organically highly polluted wastewater	50 – 85	5,0 – 8,5
Biogas from agricultural fermentation plants	55 – 70	5,5 – 7,0
Biogas from biowaste fermentation plants	55 – 65	5,5 – 6,5
Biogas from waste deposits	55 – 60	5,5 – 6,0
Biogas from renewable raw materials (NawaRo)	45 – 55	4,5 – 5,5

According to current knowledge, the biogases produced during the anaerobic degradation of sewage sludge, organically highly contaminated production wastewater, agricultural residues and organic municipal waste do not contain any environmentally relevant impurities worth mentioning apart from H_2S. The content of H_2S in biogas ranges from approx. 10 mg/m³ to 10,000 mg/m³, depending on the source substrate. Biogases are saturated with water vapour due to their formation and the condensates are generally corrosive. For certain types of biogas processing or utilisation, it may be necessary to treat a biogas contaminated with hydrogen sulphide. [18]

Combined heat and power unit (CHP) is energy efficient technology, what is simultaneous production of two forms of energy, heat and electricity, with the utilization of the waste heat generated. In grid-parallel operation, only the electrical energy that exceeds the electrical energy demand is taken from the public grid. If the electricity generated by the unit exceeds the electrical energy demand, it is fed into the grid. In isolated operation (rarely practised), the CHP unit is assigned to fixed consumers independently of the grid. Asynchronous machines are mainly used as generators for small CHP units, synchronous machines for large systems. In base-load operation, the operating mode of the gas engines is oriented to the average biogas production. Peak operation takes place when, for economic reasons, electricity generation is given priority during certain hours of the day. By utilising the biogas storage capacity and operating the reserve machines, own power generation is deliberately increased during these hours of the day. [18]

The methane component of biogas is used as a propellant to operate vehicles. Vehicles that have already been converted to run on natural gas, some of them with petrol engines, can be used. Operation with gas diesel engines is also possible. In both cases, it is possible to switch from propellant gas operation to liquid fuels during the journey. [18]

4.2.2 Methane emissions from anaerobic digestion

Anaerobically treated wastewater contains dissolved digester gas. The methane it contains remains unused as an energy source and is released into the atmosphere as a harmful greenhouse gas. The DiMeR process was developed to efficiently remove gases from the water phase, to utilise them specifically for energy and to render them harmless. The DiMeR process is used to dissolve gases that are produced in the anaerobic conversion of organic pollutants (COD) and are contained in water or sludge streams. The principle of operation is vacuum, which leads to an outgassing of the dissolved components by reducing the partial pressure. To achieve a high efficiency of gas transfer, the sludge must be exposed to a high surface area and turbulence, as the degassing rate is surface related. [19]

4.2.3 Methane emissions from anaerobic wastewater treatment (dissolved methane in reactor effluent)

SOUZA et al. (2011 and 2012) measured the dissolved methane in the wastewater of pilot-scale UASB reactors using an adapted head space method according to ALBERTO et al. (2000) and HARTLEY AND LANT (2006). They measured an average of between 19.2 and 22 mg CH_4 dissolved/L in the reactor effluent (15 to 40 cm below the free water level in the settling area), depending on the hydraulic retention time. Compared to the theoretical saturation concentration, which is calculated on the basis of the methane concentration in the biogas, this corresponds to an average degree of supersaturation between 1.37 and 1.64. The dissolved methane in the effluent corresponded to between 36% and 41% of the total methane produced in the reactor. Thereby, the amount of methane recorded in the 3PA was between 0.14 and 0.15 L CH_4/g CODelim.

SOUZA et al. (2011 and 2012) further report that between the settling zone and the effluent collection shaft (downstream of the collection flume), more than 60% of the dissolved methane and more than 80% of the dissolved hydrogen sulphide were already outgassed and emitted to the atmosphere. [20]

4.2.4 Nitrous oxide emissions from N-elimination

Nitrous oxide (N_2O) is a greenhouse gas that can be formed during nitrogen removal at wastewater treatment plants and emitted into the atmosphere. It has been shown that the ammonium oxidizing bacteria in aerated phases and due to the environmental conditions (high nitrite concentrations, high sludge load, low oxygen concentrations) always form N_2O. In contrast, the amount of N_2O produced during denitrification depends on the environmental conditions (the most important requirement: low nitric acid concentration) and even at low COD/N ratios or in the absence of rapidly decomposing carbon. Certain interfering factors have an inhibiting influence on the N_2O reduction process, causing N_2O to initially accumulate in the liquid phase and immediately emit as a gas due to low saturation concentration. The basic assumption is that N_2O accumulation and, if applicable, emission is caused by highly variable conditions and a disturbance of biological processes. The most important factors include: low oxygen concentration (during nitrification and denitrification) and high nitrite concentrations during denitrification. The proportion of N_2O formed and emitted can account for 0.01% to 15% of the nitrogen influent load of a wastewater treatment plant. Due to its global warming potential, its ozone-depleting effect and its long residence time in the atmosphere, N_2O is one of the most relevant greenhouse gases contributing to global warming. [21]

5 Summary

Continuous energy consumption is a daily activity and greenhouse gas mitigation is being pursued consistently in various climate models. European Union's climate key targets for 2030 are reduce greenhouse gas emissions at least 40% compared to 1990 levels and improvement energy efficiency at least 32,5%. The carbon footprint (CF) refers to the sum of all GHGs caused directly or indirectly by a person, an organisation, the implementation of an event, an occurrence or the manufacture of a product. The product carbon footprint describes the balance of GHG emissions along the entire life cycle of a product in a defined application and in relation to a defined unit of use. The calculation of the carbon footprint distinguishes between direct and indirect emissions. The following factors are typically taken into account in the calculation for the construction and operation of a plant and represent the indirect emissions: goods and materials used in construction, travel activities of those involved in the construction, chemicals used in operation, transport required for delivery, operating energy, waste and GHGs generated during operation and other operating materials.

The case study of the paper mill wastewater treatment plant showed that GHG emissions from industrial wastewater treatment plants during construction are negligible compared to the 20-year operating costs of the plant. The main part of the operating costs in the wastewater treatment plant was electricity demand and the consumption of chemicals. Considering the lifetime of the wastewater treatment plant, the case study revealed that the plant is CO_2 neutral due to anaerobic treatment technology. As a result, the anaerobic wastewater treatment plant has a great advantage over the aerobic treatment process, as it creates the possibility to use the generated biogas instead of fossil fuels.

In order to assess energy efficiency, it is necessary to evaluate the whole process on a “cradle-to-grave” to get over the view entire life cycle of the plants and a realistic overall picture. The recording and optimisation of the energy efficiency of wastewater plants is carried out in two steps with different processing depth and objectives.

First one is energy check, what is regular energy inventory of a wastewater system based on a few characteristic values that can be determined (giving initial orientation). The energy check is carried out by comparison with undercutting frequencies that illustrate the range of the determined characteristic values on the basis of real operating data. The purpose of the energy check is to take stock of the energy consumption of a wastewater treatment plant and to determine its initial position with regard to energy consumption and energy generation. The most obvious deficits can be identified from the results of the energy check, but without reliable quantitative statements and without detailed determination of causes (this is provided by the energy analysis). Decisive for the success of the energy check are the quality of the data basis and the clear definition of the system boundary. The values presented in the report are based on data from German wastewater treatment plants, where data of the total specific electricity consumption are currently the greatest.

Secondly, there is the energy analysis, what examines the energy situation with regard to electricity and heat, comparing the consumption values with the reference and generation values. The energy analysis shall develop optimisation measures, including a comparison of the cost framework with saved energy and operating costs. Compared to the energy check, the energy analysis requires a much more comprehensive and in-depth consideration of the wastewater plant, taking into account the machine, process, procedure and construction technology. The main stages of energy analysis are as follows:

- inventory of the current condition (documentation, process scheme, plant inspection and description, list of aggregates, energy check etc),
- creation of a consumer matrix and energy balance of the actual state (determination of the active electrical energy balance),
- determination of the plant related ideal values (annual mean values),
- assessment of the current state and identification of measures (actual condition vs plant-related ideal values, determining the differences, possible starting points),
- determining the saving potential and the economic efficiency of the measure (description of measures, profitability analysis, saving potential, the expenditure; cost-benefit ratio),
- formation of packages of measures according to priority (proposals for monitoring success - immediate, short-term and dependent measures),
- reporting (structure based on the work steps of the energy analysis).

The final chapter outlines the direct and indirect emissions associated with the process and possible technologies to reduce GHG emissions. Indirect emissions: aerobic and anaerobic digested sludge stabilization (possible opportunities), anaerobic pre-treatment of industrial wastewater (reduction aeration energy and biogas production), deammonification (reduction C and aeration demand), co-digestation (increasing of digester gas yield), heat recovery (support low-temperature sludge drying), hydraulic energy recovery (energy savings), solar drying, desulfurization of digester gas by microaeration (increased biogas potential, dewatering quality, lower costs) and optimization of aeration (energy saving, optimization). Direct emissions: digester gas flare and CHP, methane emissions from anaerobic digestion, methane emissions from anaerobic wastewater treatment (dissolved methane in reactor effluent) and nitrous oxide emissions from N-elimination.

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