AH Consult

LINKING OF THE ENERGY AND WATER SECTOR IN URBAN SYSTEMS

–

POTENTIAL IN WASTEWATER TREATMENT PLANTS

Alfred Helble

Content

1. Legal framework for municipal and industrial wastewater treatment in Germany and Europe
2. General data water supply, wastewater treatment (Germany)
3. Energy consumption and energy efficiency in municipal WWTP
4. Dynamic process control and improved automation in the wastewater and sludge treatment processes
5. Wastewater treatment processes, advanced treatment and treated effluent reuse
6. Conclusions and Visions

AH Consult

1. Legal framework for municipal and industrial wastewater treatment in Germany and Europe

- **The Water Framework Directive (WFD)** *(Wasserrahmenrichtlinie (WRRL)* was adopted on 23 October 2000 to **harmonize European water protection law**.

- In § 57 WHG (German Federal Water Act), the use of a process according to the state of the art is prescribed as a **minimum requirement** level for limiting the pollutant load of the waste water (concretized in a federal wastewater directive (17 June 2004) by means of **specific annexes** (**municipal wastewater annex 1, industrial wastewater annex 2 – 50)**.

- The most relevant regulation applying directly to the operation of **industrial plants** in the European Union is the ***Directive for Integrated Pollution and Prevention Control (IPPC)***, adopted in 1996.

- Core element for implementation of this directive into **national laws** and prerequisite for permission of industrial plants in the EU member states is the application of the ***best available techniques BAT*** documented for the respective key industries in the ***Best Available Technique Reference Documents BREF*** (BREF 2015) with transposition until **September 2018).**

AH Consult

1. Legal framework, wastewater directive, annexe 1 municipal wastewater

The following table shows the requirements for municipal sewage treatment plants according to Annex 1 to the Waste Water Directive (to be observed in the 2 h composite sample or qualified grab sample, correspond to 95-percentile values, in four out of five cases (AbwV § 6 Abs. 1) according to to the size classes (GK = Größenklasse = size class)

GK 1 ‹ 1,000 population equivalents (p.e.)

GK 2 › 1,000 - 5.000 p.e.

GK 3 › 5,000 - 10.000 p.e.

GK 4 › 10,000 - 100.000 p.e.

GK 5 › 100,000 p.e.

[Verordnung über Anforderungen an das Einleiten von Abwasser in Gewässer (Abwasserverordnung - AbwV)) vom 17. Juni 2004 (BGBl. I S.1108) zuletzt geändert durch Artikel 121 des Gesetzes vom 29. März 2017 (BGBl. I Nr. 16, S. 626) in Kraft getreten am 5. April 2017]*

1. Legal framework, wastewater directive, annexe 1 municipal wastewater

Treated effluent standards for municipal WWTPs

Größenklasse der Abwasser-behandlungs-anlagen bzw. GK or BOD_5 (raw)-load	Ausbau-größe in Ein-wohner- p.e.	Chemischer Sauerstoff-bedarf COD mg/l	Biochem. Sauer-stoff-bedarf BOD_5 mg/l	Ammo-nium-stickstoff N-NH_4 mg/l	Stick-stoff gesamt N-total mg/l	Phos-phor gesamt P-total mg/l
Größenklasse 1 < 60 kg/d	< 1.000	150	40	-	-	-
Größenklasse 2 60 bis 300 kg/d	1.000 bis 5.000	110	25	-	-	-
Größenklasse 3 > 300 bis 600 kg/d	5.001 bis 10.000	90	20	10	-	-
Größenklasse 4 > 600 bis 6.000 kg/d	10.001 bis 100.000	90	20	10	18	2
Größenklasse 5 > 6000 kg/d	> 100.000	75	15	10	13	1

2. General data water supply, wastewater treatment (Germany)

Water supply (domestic) 2010:
- water utilities > 6,000
- water volume:

~ 5.1 billion m³
- Individual spec. water consumption 2016

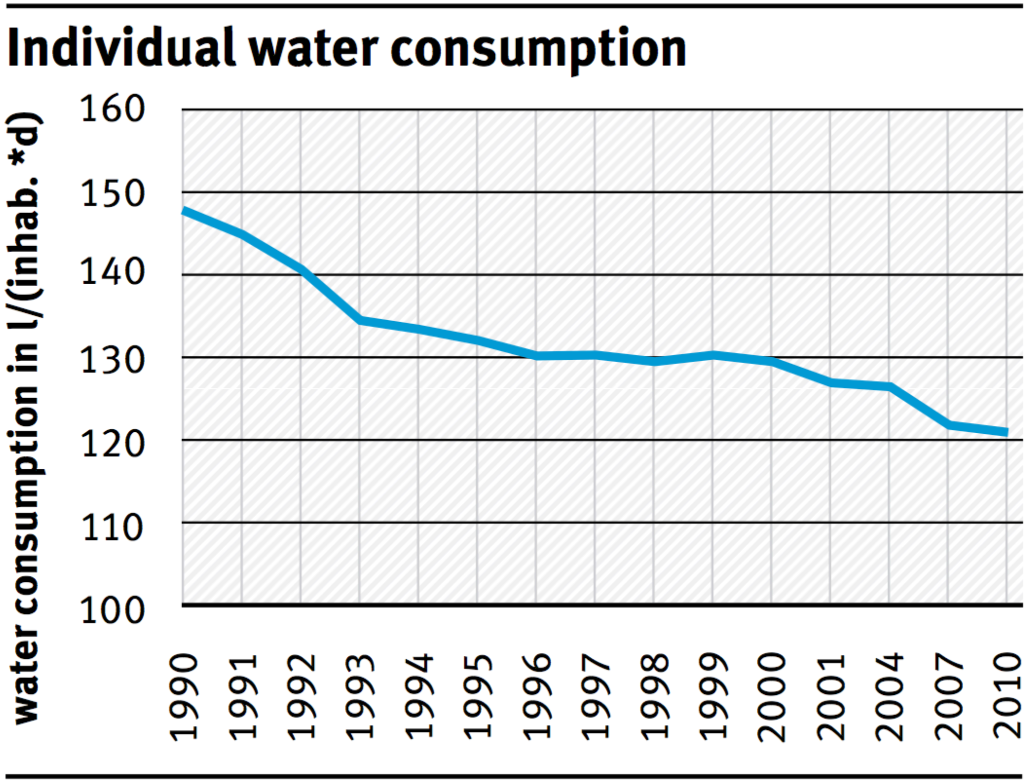
123 l/(Inhab.*d)

[https://de.statista.com/statistik/daten/studie/12353/umfrage/wasserverbrauch-pro-einwohner-und-tag-seit-1990/]

Municipal wastewater:
- More than 6,900 wastewater disposal comp operate a total of approx. **10,000 WWTPs**
- A total of approx.

10 billion m³ per year
of wastewater was treated
in 2010.

[wawiflyer_uba_en_web, 2013]



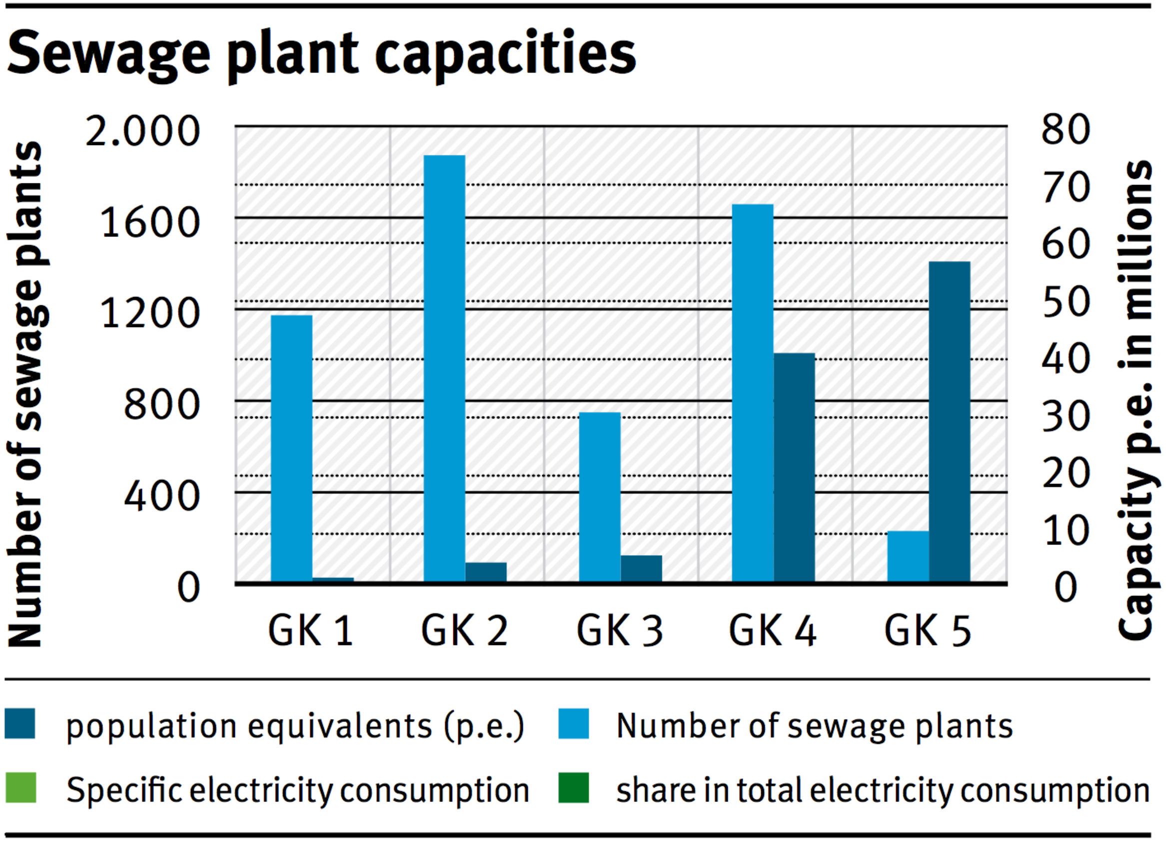
Source: Federal Statistical Office, 2013

2. General data water supply, wastewater treatment (Germany)

Municipal wastewater:
- Around 78 million inhabitants are connected to centralized WWTPs

[wawiflyer_uba_en_web]

Industrial wastewater:
- Approx. **3,000 WWTPs** are operated before indirect or direct discharge
- Treated wastewater volume is almost **0.92 billion m³** (without cooling water). In contrast to the municipal sewage treatment, the **wastewater characteristics and loads vary significantly**.



[Marktstudie Industriekläranlagen Deutschland, Köln / Oberhausen, Dezember 2010]

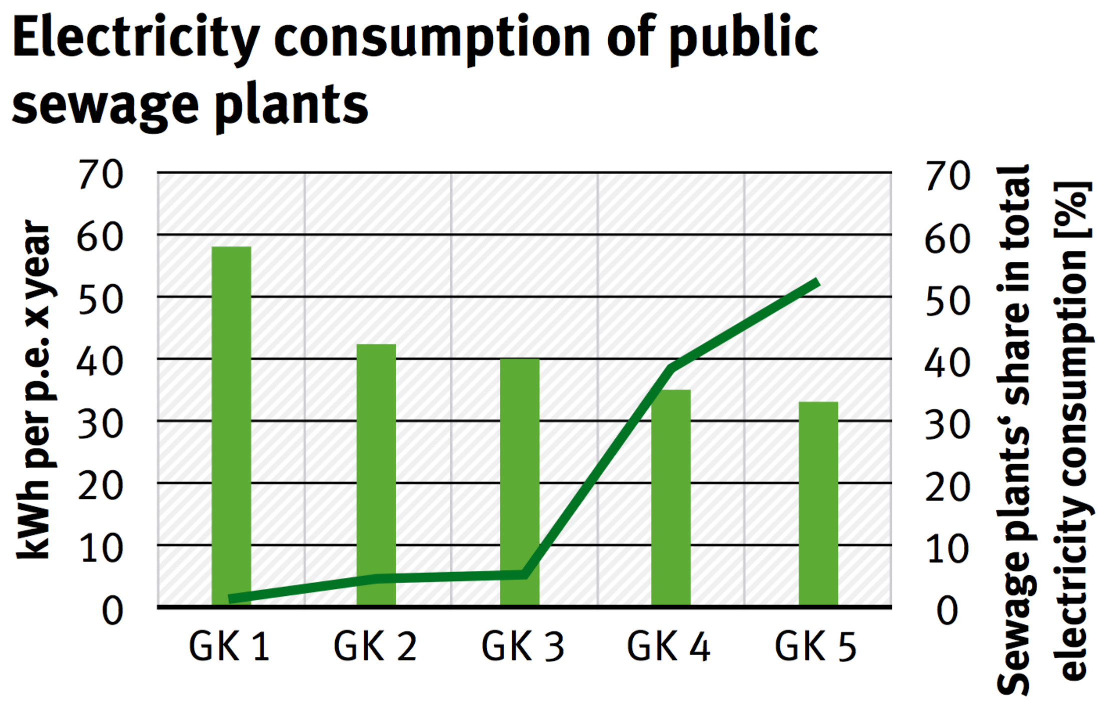
3. Energy consumption, production and energy efficiency in municipal WWTP (Germany)

Municipal wastewater:
- **WWTPs** are one of the **biggest consumers of electricity**.
- The almost 10,000 WWTPs (approx. 119.7 mio p.e.) consume around 4,400 (GWh)/y (0.84 % related to 525 TWh/y 2016).

- Category 4 and 5 represent 2,200 WWTP (out of 10,000) treat over 92 % of p. e. accounts for 90 % of the total energy consumption but have significantly lower specific electrical consumption.

- CO_2 emmission total amounts to approx. 2.2 mio t/y

[wawiflyer_uba_en_web]



GK 1 ‹ 1,000 population equivalents
GK 2 › 1,000 - 5.000 population equivalents
GK 3 › 5,000 - 10.000 population equivalents
GK 4 › 10,000 - 100.000population equivalents
GK 5 › 100,000 population equivalents

Source: German Association for Water, Wastewater and Waste, 2011

3. Energy consumption and energy efficiency in municipal WWTP (on the example of South Germany BW)

Energy production related to the WWTP size classes amounts as median to 13.7 kWh/(p.e.*y) 2013.

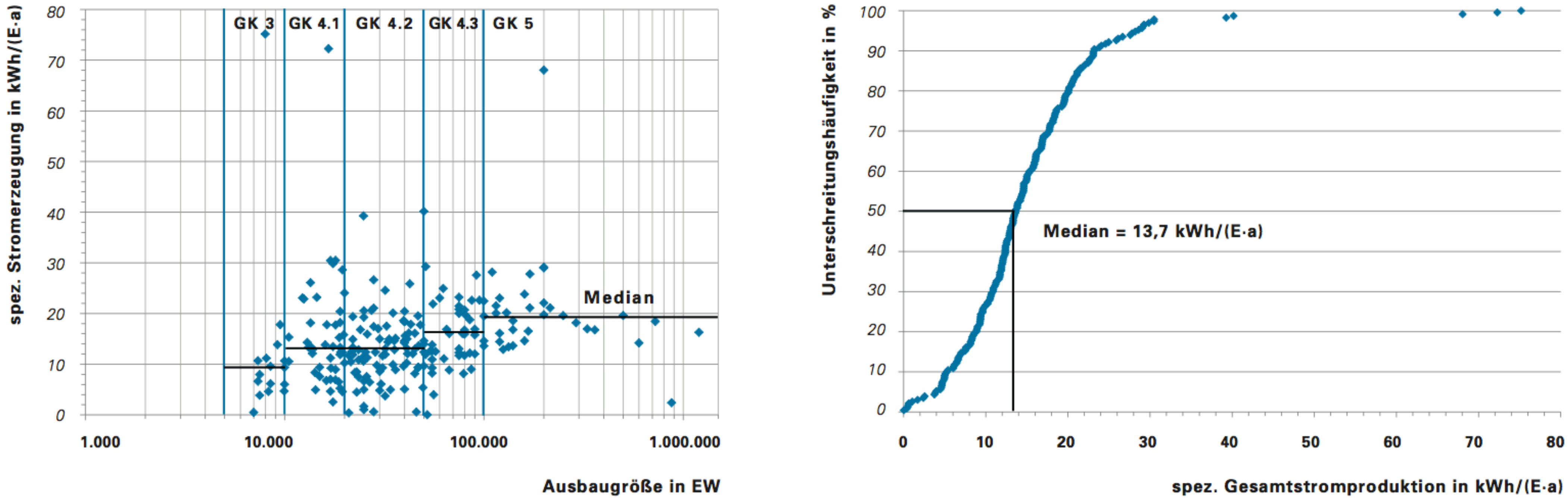


Abb 10: *Spezifische Stromerzeugung (n = 230, DWA-Leistungsvergleich BW, 2013)*

[151010_Leitfaden_Energieeffizienz_auf_Klaeranlagen.pdf, 2015]

3. Energy consumption, production and energy efficiency in municipal WWTP (on the example of South Germany, BW)

Energy consumption related to the WWTP size classes median approx. 35 kWh/(pe*y).

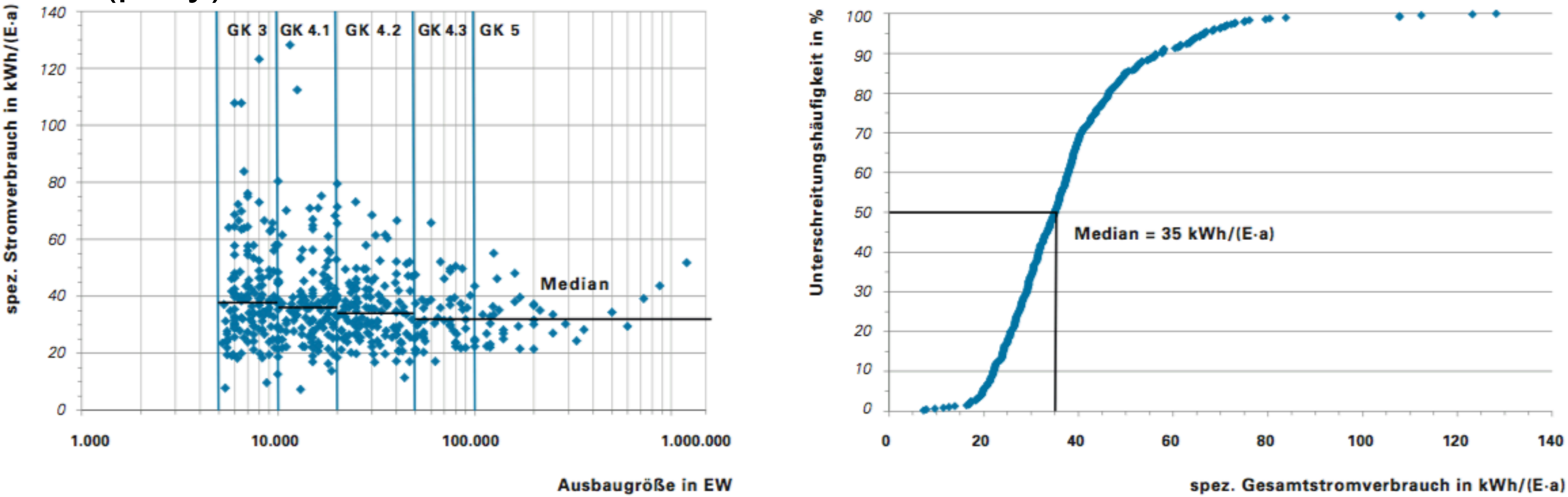


Abb 9: *Spezifischer Gesamtstromverbrauch (n = 483, DWA-Leistungsvergleich BW, 2013)*

[151010_Leitfaden_Energieeffizienz_auf_Klaeranlagen.pdf, 2015]

3. Energy consumption, production and energy efficiency in municipal WWTP (on the example of South Germany BW)

Saving potentials in electricity consumption related to the WWTP size classes is expected to be in average approx. 18 %. However, objective is to achieve 30 kWh/(p.e.*y) or lower (best case < 20 kWh/(p.e.*y).

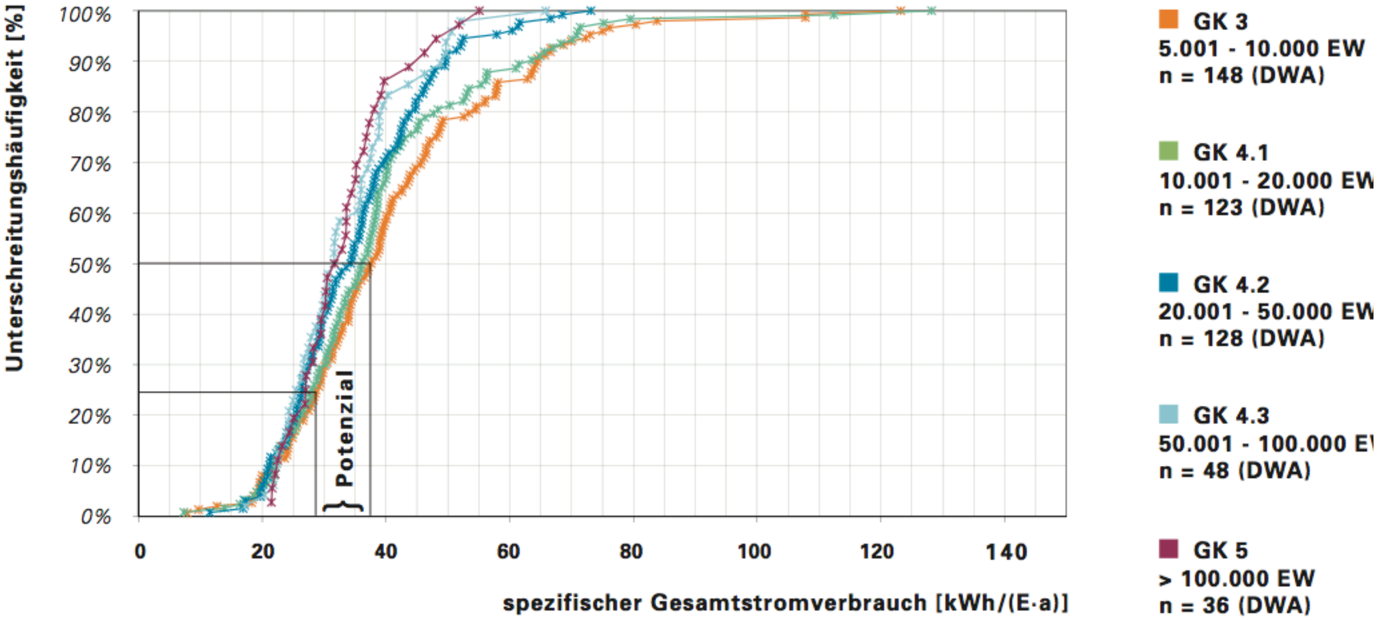


Abb. 15: *Theoretische Abschätzung des elektrischen Einsparpotenzials durch Vergleich mit Perzentilwerten (DWA-Leistungsvergleich BW, 2013)*

Tabelle 5: *Theoretisches Einsparpotenzial auf Basis der DWA-Daten (DWA-Leistungsvergleich BW, 2013)*

Größen-klasse	Stromeinsparpotenzial kWh/(E·a)	GWh/a	% vom IST-Wert
GK 3	*8,6*	*8,3*	*24,6*
GK 4.1	*8,0*	*12,1*	*21,8*
GK 4.2	*7,9*	*21,1*	*20,1*
GK 4.3	*5,5*	*14,1*	*17,7*
GK 5	*5,2*	*32,6*	*15,1*
Gesamt	*6,3*	*88,2*	*18,0*

[151010_Leitfaden_Energieeffizienz_auf_Klaeranlagen.pdf, 2015]

AH Consult

3. Energy consumption and energy efficiency in municipal WWTP (on the example of South Germany BW)

Measures to achieve the saving potentials in electrical consumption related to the WWTP size classes.

1 Upgrade of CHP in existing digesters, GK 1, GK 4
9.8 – 14.5 kWh/pe*y

2a Optimisation of electricity yield GK 4
14.5 - 17.0 kWh/pe*y

2b Optimisation of electricity yield GK 5
18.0 - 17.0 kWh/pe*y

3 Change aerobic to anaerobic sludge stabilisation GK 3, GK 4.1 and GK 4.2
9.8 kWh/pe*y (GK 3), 14.5 kWh/pe*y (GK 4.1 and GK 4.2)

4 Best case (Combination 1, 2b, 3)
9.8 kWh/pe*y (GK 3), 17 kWh/pe*y (GK 4), 21.0 kWh/pe*y (GK 5)

[151010_Leitfaden_Energieeffizienz_auf_Klaeranlagen.pdf, 2015]

3. Energy consumption, production and energy efficiency in municipal WWTPs (Germany total)

Sewage gas 2013:

- Total 5,725,425 Mwh/y
- Self-consumption for electricity 4,569,214 Mwh/y
- Electricity production 1,198,175 Mwh/y
- Available for external use 195,601 Mwh/y

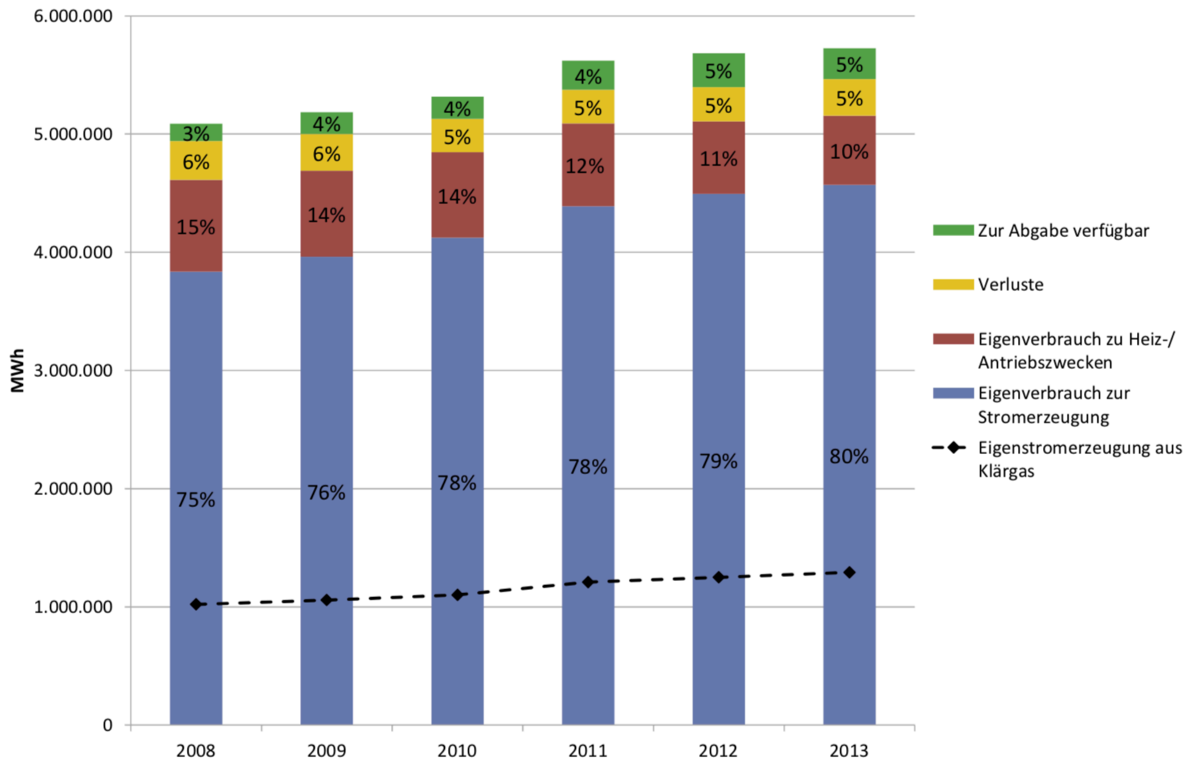


Abb. 11: Gewinnung, Verwendung und Abgabe von Klärgas in Deutschland 2008–2013 [MWh] [43]

[KA Korrespondenz Abwasser, Abfall · 2015 (62) · Nr. 1]

AH Consult

3. Energy consumption, production and energy efficiency in municipal WWTP (sewage gas)

- As a result of the considerable price increases in external electricity, operators of sewage treatment plants with anaerobic sludge stabilization are increasingly striving for **electricity self-sufficiency** using **co-fermentation.**

- The **intensified co-fermentation or the increase of the biogas yield** in general offers **by far** the highest potential as an individual measure.

- However, a far reaching **additional biogenic substrate supply** is required (such as sludges from sewage treatment plants with aerobic stabilization or external waste and concentrates).

- The intensified co-fermentation in connection with a complete power generation with efficient CHPs might increase the electricity production by factor 3 (2 – 4) (self-sufficent operation).

3. Energy consumption, production and energy efficiency in municipal WWTP (sewage gas)

- As a consequence, the **heat surpluses** which actually occur temporarily during the course of the year when using the generated sewage gas **in CHP plants** would **significantly increase**.

- A treatment of the sewage gas to natural gas quality with a subsequent feed of the generated "bio-methane" in the public gas network could allow a more efficient use of the **primary energy potential**

and

- could alternatively favour the **external sourcing of electrical energy.**

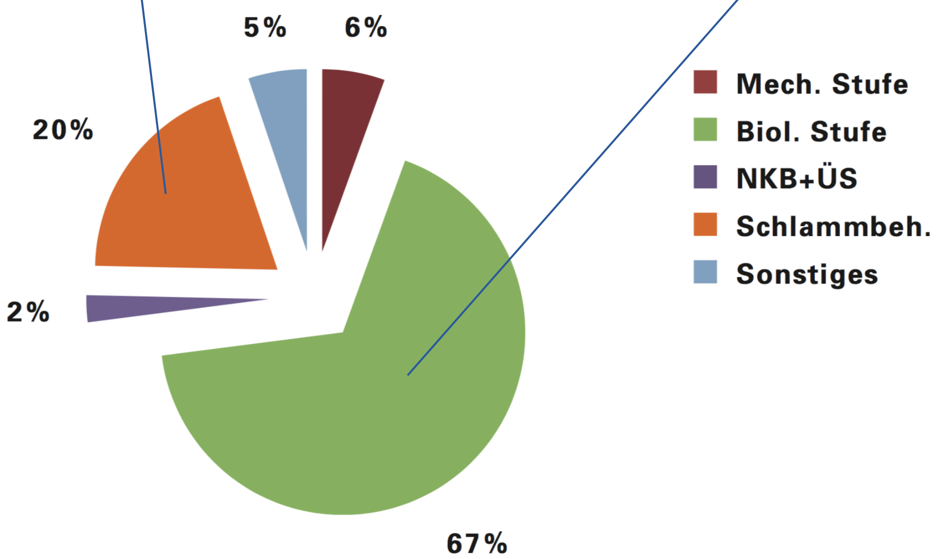
4. Dynamic process control and improved automation in the wastewater and sludge treatment processes

Percentage distribution of mean specific electricity consumption to the individual process groups (**on the example of South Germany, BW**). **Sludge treatment** and **biological stage** to be considered **for dynamic process control and improved automation**.

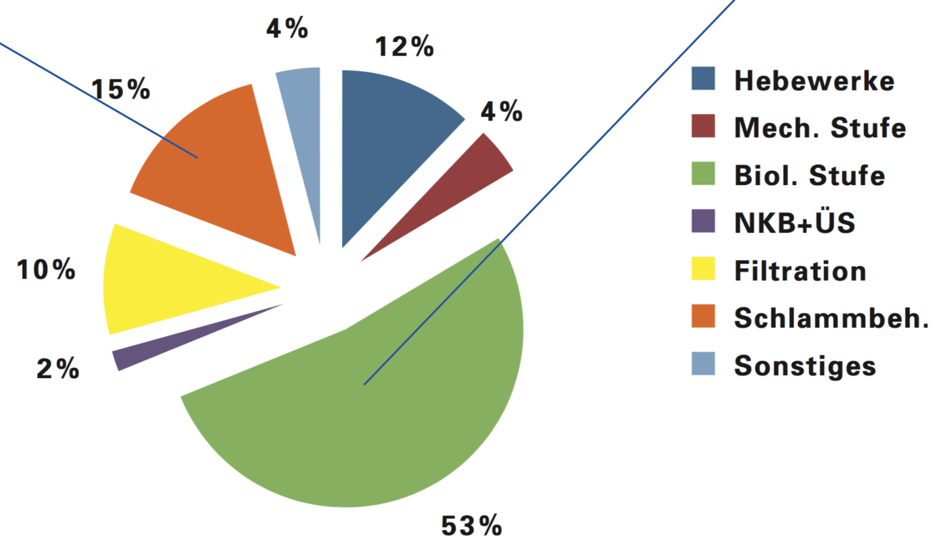
Sludge treatment

Biological stage (mainly for aeration activated sludge tank)

Without main lifting stations and tertiary filtration



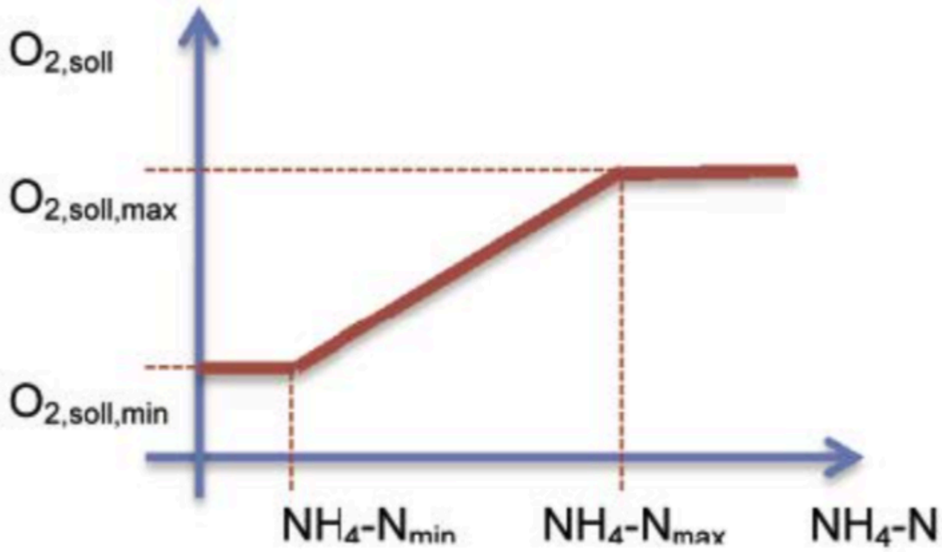
With main lifting stations and tertiary filtration included

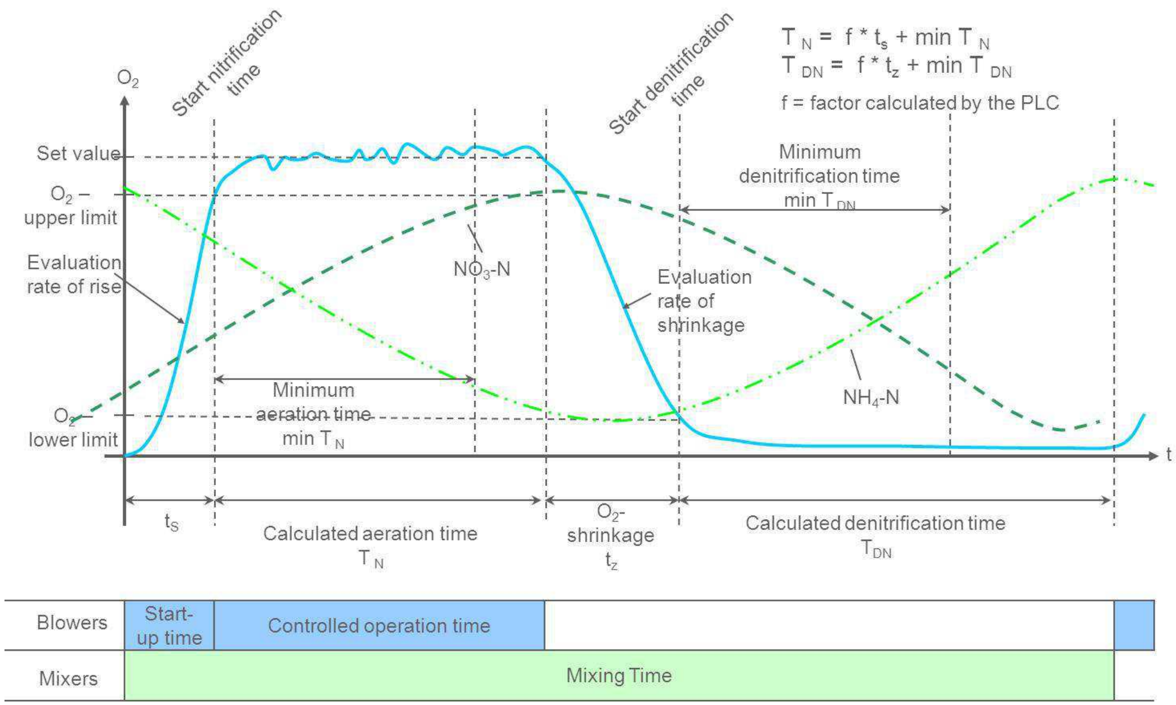


[151010_Leitfaden_Energieeffizienz_auf_Klaeranlagen.pdf, 2015]

4. Dynamic process control and improved automation in the wastewater and sludge treatment processes

Example 1: An improved aeration and blower control for oxygen supply needed for nitrification **adopted to the individual daily hydrographs** in wastewater might help to better compensate natural fluctuations during renewable energy production. Online sensors (N, P) and p**redictive software** analytics and simulation is required.



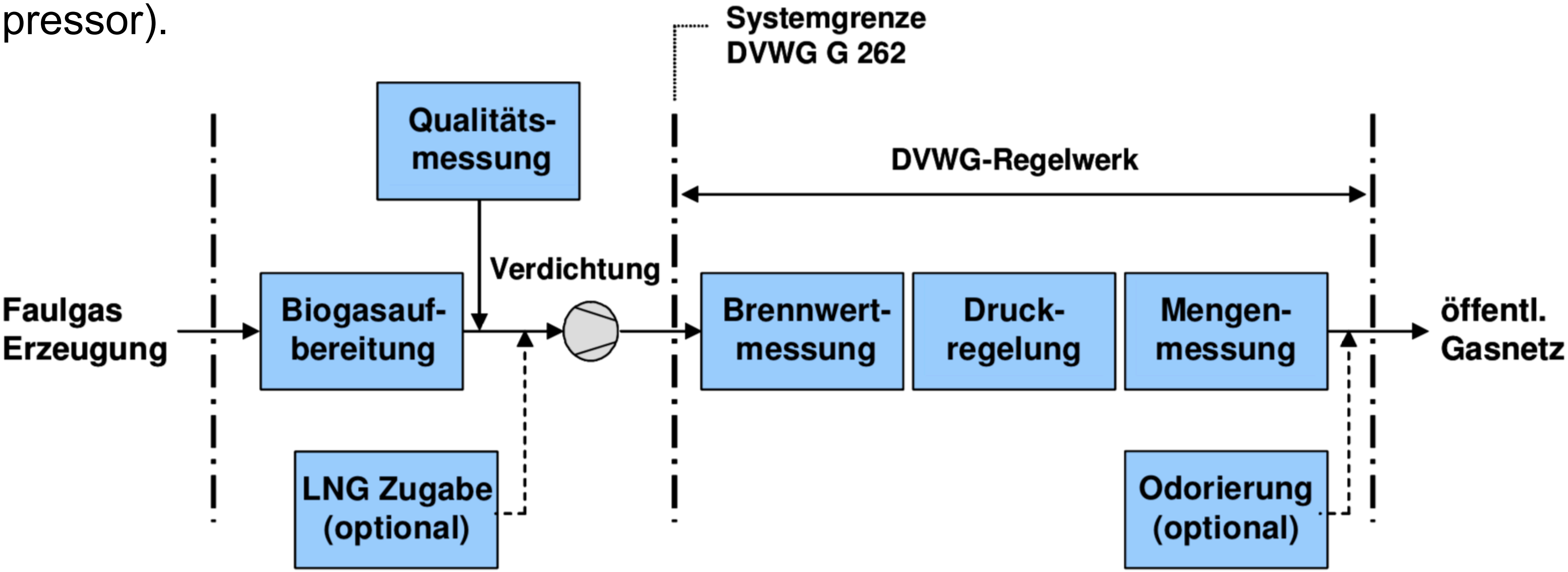


[Common graphical figures according to state of art for oxygen, nitrification and denitrification process control in WWTP operation, 2017]

AH Consult

4. Dynamic process control and improved automation in the wastewater and sludge treatment processes

Example 2: Controlled sewage gas production by increased sludge digestion, increased sewage gas purification to natural gas and direct supply as bio-methane after pressure boosting into the compressed natural gas (CNG) grid (with renewable energy for gas compressor).



CH4 in Sewage gas approx. 60 %   CH4 in bio-methan gas approx. 99.5 %

[StudieFaulgasAbschlussbericht, 2011]

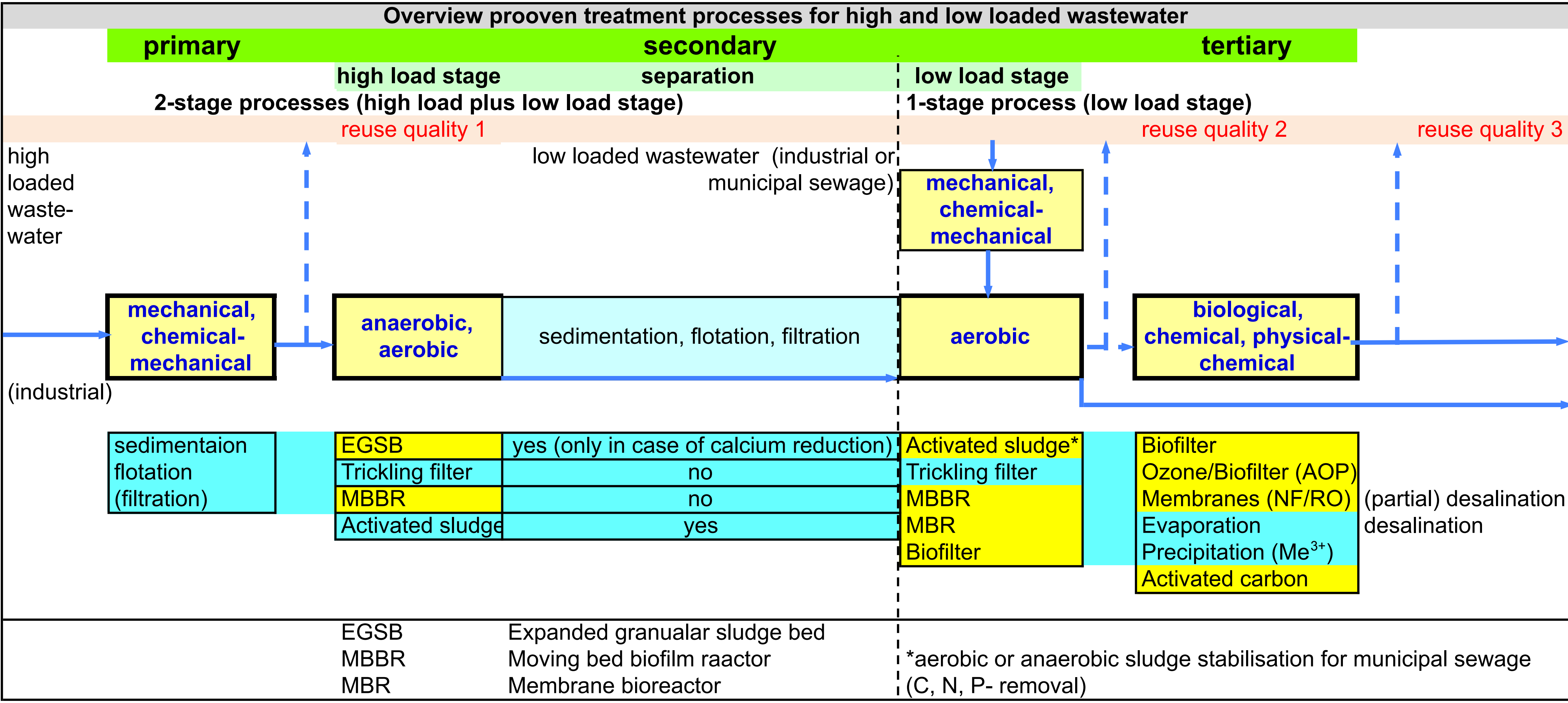
5. Wastewater treatment processes, advanced treatment and treated effluent reuse

- The availability of water in the quality **either for irrigation** in the **agriculture sec**tor, **as freshwater or process water** for diverse applications and **the availability of surface and ground water for drinking water** supply, is a key factor in order to ensure a sustainable growth of urban infrastructures.

- **Micro pollutants** and **organic persistent compounds** have to be eliminated before discharge to the receiving waters and for an **inevitable capacity increase in treated effluent reuse** (water shortage due to climate change)**.**

- Overall concepts must be developed using the ***best available technologies*** (BAT) for secondary wastewater treatment as a **prerequisite for the efficient and economic operation of advanced treatment** (including emerging techniques such as ***advanced oxidation processes*** (AOP)) **.**

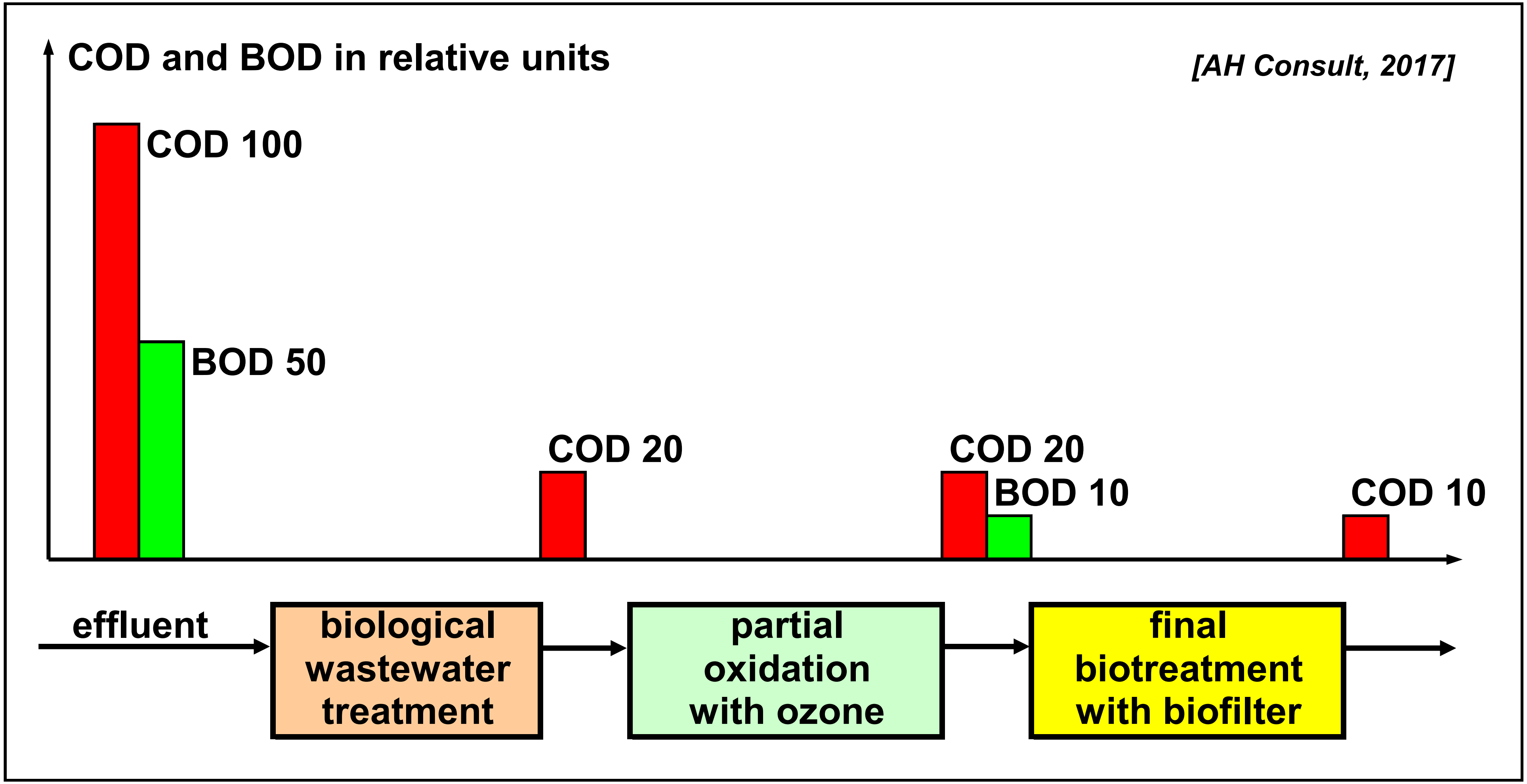
5. Wastewater treatment processes, advanced treatment and treated effluent reuse



[AH Consult, 2017]

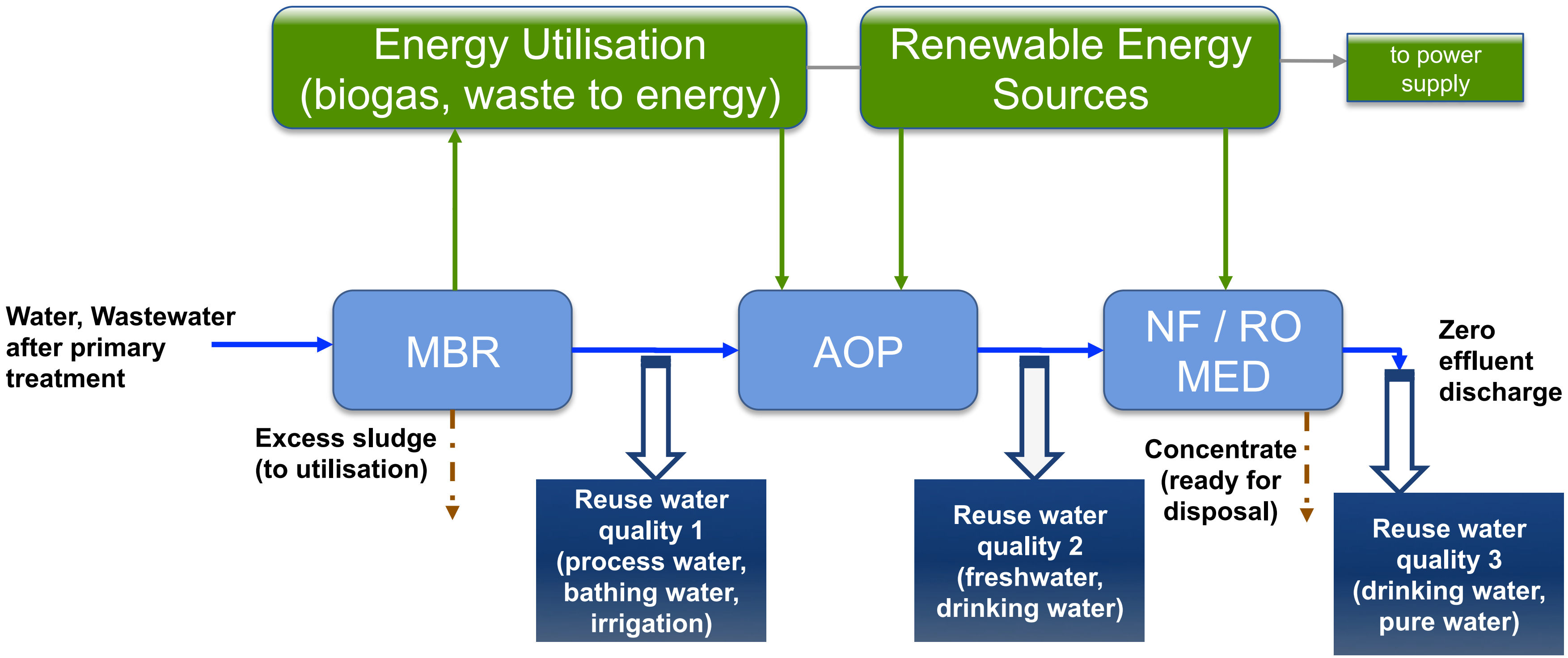
6. Wastewater treatment processes, advanced treatment and treated effluent reuse

Tertiary treatment with advanced oxidation process (AOP):
Here: Ozonation in combination with biofiltration



6. Wastewater treatment processes, advanced treatment and treated effluent reuse

Schematic flow sheet with innovative water treatment technologies for treated effluent reuse



MBR membrane bioreactor technology
AOP advanced oxidation processes
NF, RO nanofiltration, reverse osmosis for desalination
MED multi effect destillation processes for desalination

[AH Consult, 2017]

AH Consult

6. Conclusions and Visions

- The **further energetic optimisation** of systems (pumps, mixers, CHP) and the systematic process modification from aerobic to anaerobic sludge stabilisation also for size classes down to GK 3 (5,000 – 10,000 p.e.) can provide an additional energy efficiency increase of approx. 18 % for municipal WWTP.

- An increase of the electricity production by **factor 3 (2 - 4) by co-fermentation** and a treatment of the sewage gas to natural gas quality with a **subsequent feed of the generated bio-methane into the public natural gas grid** could allow a more efficient use of the primary energy potential **besides** the objective an energetic self-sufficient operation of the WWTP.

- **Dynamic process control and improved automation** in the wastewater and sludge treatment processes adapted to the availability of renewable energy might help to stabilise the grid **(sector linking).**

6. Conclusions and Visions

- **Overall concepts** must be developed using **BAT** for secondary wastewater treatment as a **prerequisite** for the **efficient and economic operation** of advanced and emerging techniques for tertiary and quaternary wastewater treatment and **treated effluent reuse.**

- The already started implementation of the 4th treatment stage in WWTP for the **removal of micro-pollutants** as well as the **implementation of mono-incineration for more efficient phosphorous removal** in the near future will increase the energy requirements again.

- The **expectation and the vision of the water experts** is, that the additional energy requirements might be compensated by the energy efficiency measures as described above.

AH Consult

Thank you for attention!

AH Consult Dipl.-Ing. Alfred Helble
Consulting Engineer
Consultant in Water, Wastewater and Environmental Technology

Dipl.-Ing. (FH) Alfred Helble
Lehenstraße 48
70180 Stuttgart
Germany

Tel. +49 711 6071381
Fax +49 711 6071389
Mobiltel. +49 160 97931254
ah@ah-consult.com
www.ah-consult.com