Operating costs and energy demand of wastewater treatment plants in Austria: benchmarking results of the last 10 years

J. Haslinger, S. Lindtner and J. Krampe

ABSTRACT

This work presents operating costs and energy consumption of Austrian municipal wastewater treatment plants (WWTPs) (≥10,000 PE-design capacity) that have been classified into different size groups. Different processes as well as cost elements are investigated and processes with high relevance regarding operating costs and energy consumption are identified. Furthermore, the work shows the cost-relevance of six investigated cost elements. The analysis demonstrates the size-dependency of operating costs and energy consumption. For the examination of the energy consumption the investigated WWTPs were further classified into WWTPs with aerobic sludge stabilisation and WWTPs with mesophilic sludge digestion. The work proves that energy consumption depends mainly on the type of sludge stabilisation. The results of the investigation can help to determine reduction potential in operating costs and energy consumption of WWTPs and form a basis for more detailed analysis which helps to identify cost and energy saving potential.

Key words | energy consumption, energy self-sufficiency, operating costs, WWTP benchmarking

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INTRODUCTION

Wastewater treatment plant (WWTP) benchmarking contributes to the identification of optimisation and cost reduction potential (Lindtner *et al.* 2008). As stated in Foladori *et al.* (2015), an energy saving potential is almost always present in WWTPs. Baumann *et al.* (2014) and Haberkern *et al.* (2008) describe target and guide numbers for the evaluation of energy efficiency of WWTPs. A detailed energy analysis can help to identify optimisation potential and to reduce energy consumption at each stage/process/unit of a WWTP, whereby the increase of energy efficiency does not involve necessarily significant investments (Foladori *et al.* 2015). Performance indicator systems for WWTPs are described in literature (e.g. Quadros *et al.* 2010; Balmér & Hellström 2012).

In Austria, a benchmarking method was developed from 1999 to 2004; the aim is the identification of best performing WWTPs and the determination of cost reduction potentials to improve the cost efficiency (Kroiss & Lindtner 2005). Within the last 10 years, almost every second Austrian municipal WWTP treating more than 10,000 population equivalents (PE, expressed as PE-design capacity) participated at least once in the annual benchmarking. With regard to PE, about 56% of the Austrian municipal WWTP capacity is included in the benchmarking data pool. The representativity of the data for all Austrian WWTPs was investigated and confirmed (Lindtner & Vohryzka 2015). This work investigates operating costs and energy consumption data from 104 Austrian municipal WWTPs (≥10,000 PE) which participated at least once in the annual benchmarking in the years 2003 to 2013, of which 16 WWTPs are treating more than 100,000 PE. All costs are indexed to the year 2013 and, in cases where a WWTP participated more than once, mean values are calculated. This work shows the results of the analysis and interpretation of the benchmarking pool data and provides an insight into operating costs and energy consumption of Austrian municipal WWTPs. All investigated WWTPs fulfil the legal requirements regarding wastewater treatment (removal of 95% biochemical oxygen demand, 85% chemical oxygen demand (COD) and 70% total nitrogen; total phosphorus threshold 0.5 or 1.0 mg/L depending on plant size and receiving water) and hence remove carbon, nitrogen and phosphorus (with nitrification/denitrification and chemical/biological P-elimination).

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METHODS

The Austrian benchmarking method is described in detail in Lindtner *et al.* (2004). To enable the comparison of WWTPs of different process and operation modes, operating costs of WWTPs are split into the following main and support processes: mechanical pretreatment (process 1; P1), mechanical–biological wastewater treatment (process 2; P2), sludge thickening and stabilisation (process 3; P3), further sludge treatment and disposal (process 4; P4), obligatory processes (support process I; SPI) and optional processes (support process II; SPII).

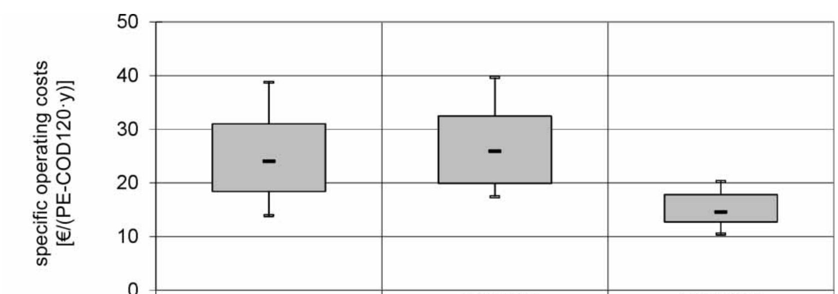
For each process, yearly specific operating costs and specific energy consumptions are calculated based on annual data provided by the plants, whereby the operating costs are split into six cost elements (i.e. personnel costs, energy costs, residue treatment costs, material costs, external costs and other costs). Specific costs and specific energy consumptions are based on the real organic pollution load (expressed in PE-COD120) of the WWTPs, because the organic pollution load correlates best with operating costs and energy consumptions, as investigated (Lindtner 2004). Furthermore, the reference value PE-COD120 is commonly used for such investigations (e.g. Haberkern *et al.* 2008; Baumann *et al.* 2014) and therefore ensures the comparison of data from different studies. The COD-population equivalents (PE-COD120) are calculated from the mean yearly COD-load of the WWTP, which is checked for plausibility with mass balances to ensure a correct reference value and the PE-specific COD-load (120 g chemical oxygen demand per person and day corresponding to 60 g biochemical oxygen demand during 5 days per person and day).

RESULTS AND DISCUSSION

Operating costs

Figure 1 illustrates the specific total operating costs of the investigated WWTPs and shows that specific operating costs decrease with increasing design capacity (economy of scale). The yearly specific operating costs of the investigated large plants (≥100,000 PE) are €14.6/(PE-COD120·y) (median) and thus considerably smaller than of WWTPs <100,000 PE.

The detailed analysis of the operating costs is shown in Figures 2 and 3. Figure 2 shows that personnel costs are the most relevant cost element at the investigated WWTPs. However, it can be assumed that the importance of personnel costs on total operating costs is highly country-specific and depends on the country-specific level of salary. Furthermore, the operational strategy influences the impact of personnel costs and external costs on total operating costs. WWTPs which employ their own staff for operation and maintenance have higher specific personnel costs and lower specific external costs compared to WWTPs which outsource operation and/or maintenance. Energy costs contribute 17% and 11% to the total operating costs of small and large WWTPs, respectively, and hence are of lower importance regarding operating costs. Energy costs depend on several (site-specific) factors, which are energy consumption, energy production and external energy costs (Lindtner *et al.* 2008). The fact that energy costs are of lower relevance regarding operating costs shows that the main reason for the minimization of energy costs is environmental aspects. However, with regard to environment protection, the reduction of energy



	all WWTPs	<100,000 PE-design capacity	≥100,000 PE-design capacity
number	104	88	16
75th percentile	31.0	32.5	17.8
90th percentile	38.8	39.7	20.3
10th percentile	13.9	17.4	10.5
median	24.1	25.9	14.6
25th percentile	18.4	19.9	12.7

Figure 1 | Specific operating costs of municipal WWTPs in Austria.

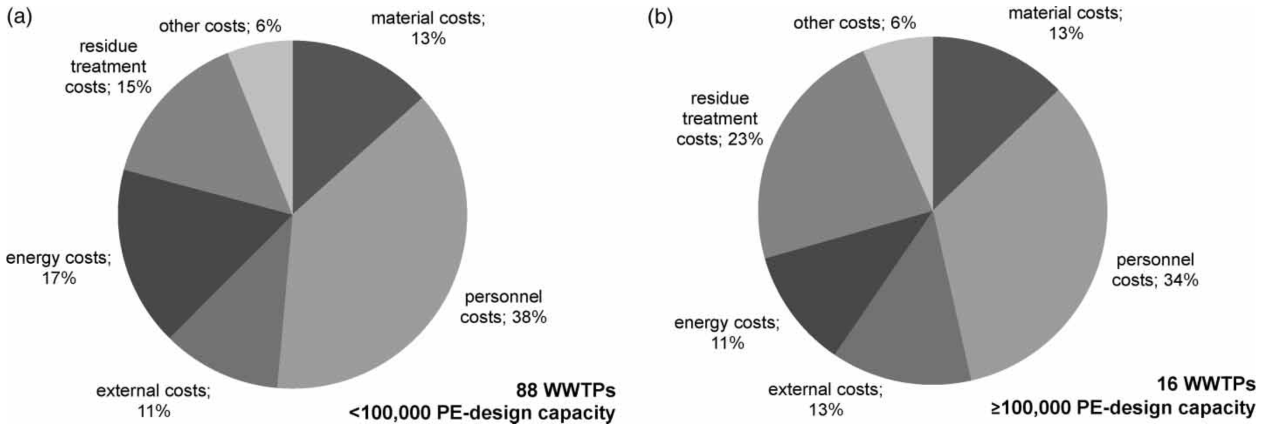


Figure 2 | Distribution of cost elements of total operating costs of small and large municipal WWTPs in Austria.

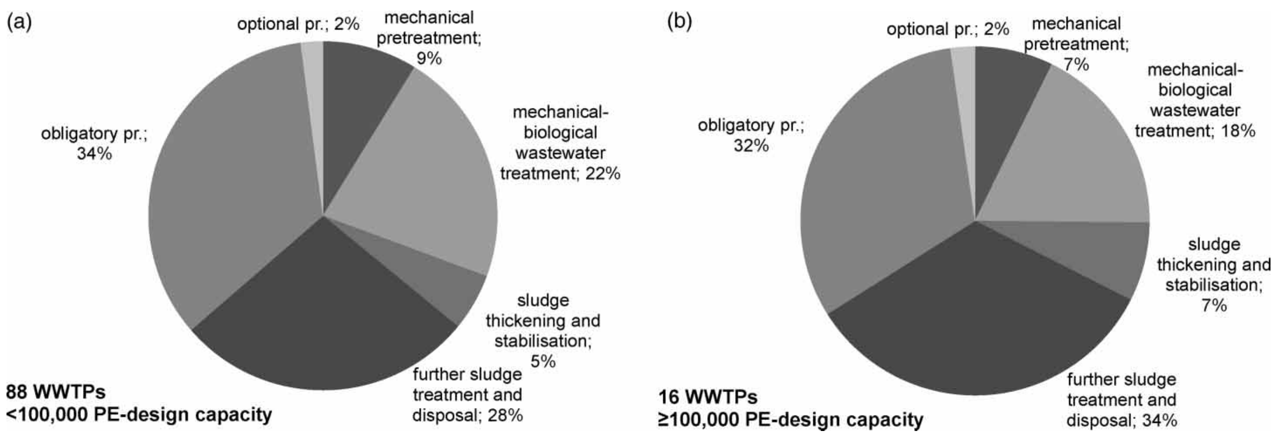
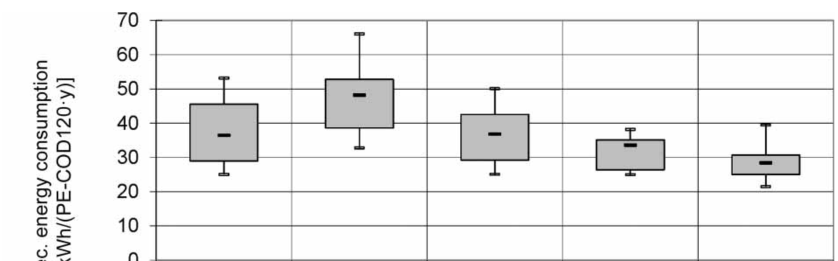


Figure 3 | Distribution of processes of total operating costs of small and large municipal WWTPs in Austria.



	all WWTPs	≥10,000-<20,000 PE-design capacity	≥20,000-<50,000 PE-design capacity	≥50,000-<100,000 PE-design capacity	≥100,000 PE-design capacity
number	102	24	55	7	16
75th percentile	45.6	52.8	42.6	35.1	30.7
90th percentile	53.2	66.1	50.1	38.2	39.5
10th percentile	25.1	32.8	25.1	25.0	21.5
median	36.5	48.2	36.8	33.6	28.4
25th percentile	29.0	38.6	29.3	26.4	25.0

Figure 4 | Specific energy consumption of municipal WWTPs in Austria (data without outliers).

Table 1 | Specific energy consumption of municipal WWTPs in Austria subdivided into WWTPs with aerobic sludge stabilisation and mesophilic sludge digestion, respectively (data without outliers)

		WWTPs			
		With aerobic stabilisation		With mesophilic sludge digestion	
Spec. energy consumption [kWh/PE-COD 120/y]	All WWTPs	≤ 50.000 PE	> 50.000 PE	≤ 50.000 PE	> 50.000 PE
Number	102	38	1	41	22
25th percentile	29.0	33.6	34.8	29.2	25.2
Median	36.5	42.2	34.8	36.8	28.4
75th percentile	45.6	49.9	34.8	42.5	34.2

consumption at WWTPs is crucial with the increase of energy production. But, as stated in Svardal & Kroiss (2011), energy minimisation must never negatively affect treatment efficiency due to the importance of water quality conservation. Furthermore, greenhouse gas emissions have to be considered if optimisation measures are planned.

Figure 3 shows that support process I (obligatory processes; i.e. laboratory and monitoring, administration, operation building and infrastructure) and process 4 (further sludge treatment and disposal; i.e. dewatering, reuse/disposal) are the most cost-relevant processes in small as well as large WWTPs. Obligatory processes are very labour-consuming and hence cost-intensive. The high costs for further sludge treatment and disposal can be explained by the costs for residue treatment (e.g. screenings, sludge). Process 2 (mechanical–biological wastewater treatment; i.e. aeration, biogas utilisation, phosphorus precipitation), the most important process with regard to water pollution control, contributes only 22% and 18% to the total operating costs of small and large WWTPs, respectively. This is due to the fact that this process is not very labour-consuming in comparison to other processes. The investigations showed that energy costs are of highest relevance for mechanical–biological wastewater treatment, which is the process with the highest energy consumption as described subsequently.

Energy consumption

For the following investigations the data of two WWTPs were excluded because of implausibility (specific total energy consumption ≤15 kWh/(PE-COD120·y)).

Figure 4 illustrates the specific energy consumption of the investigated WWTPs classified into four groups depending on their plant size. The median of the specific energy consumption of all WWTPs amounts to 36.5 kWh/(PE-COD120·y). These results confirm guide numbers from literature (e.g. Baumann et al. 2014). However, variability between the different WWTP sizes is high. The figure demonstrates the size-dependency of the energy consumption in WWTPs. One reason is that small WWTPs, especially WWTPs treating less than 20,000 PE, stabilise their sludge aerobically and therefore consume more energy.

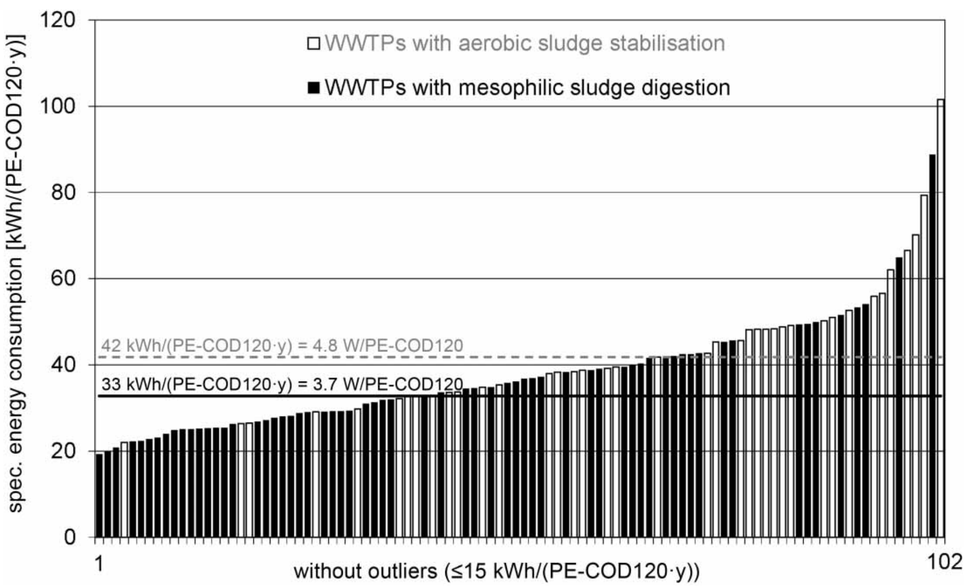


Figure 5 | Specific energy consumption and energy demand of municipal WWTPs in Austria (data without outliers).

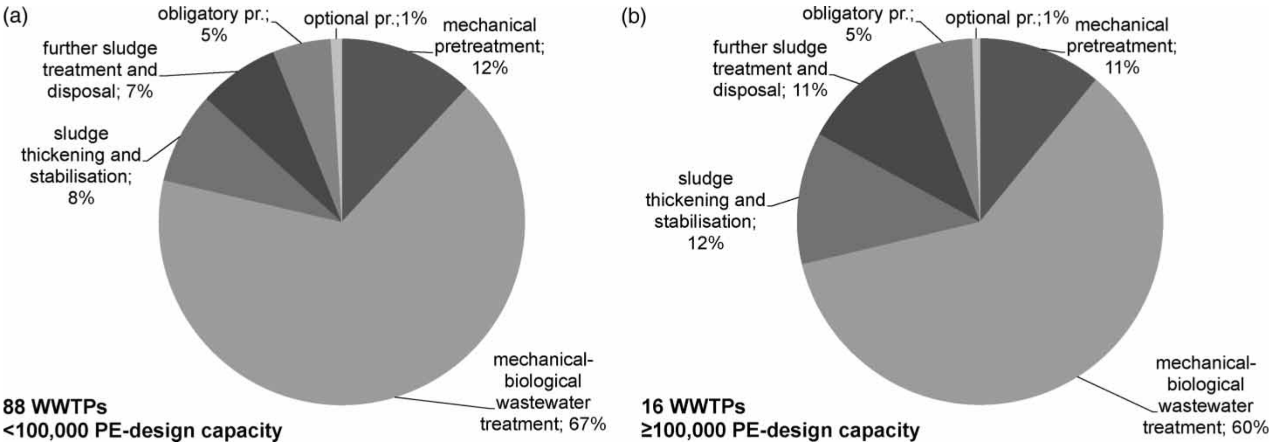


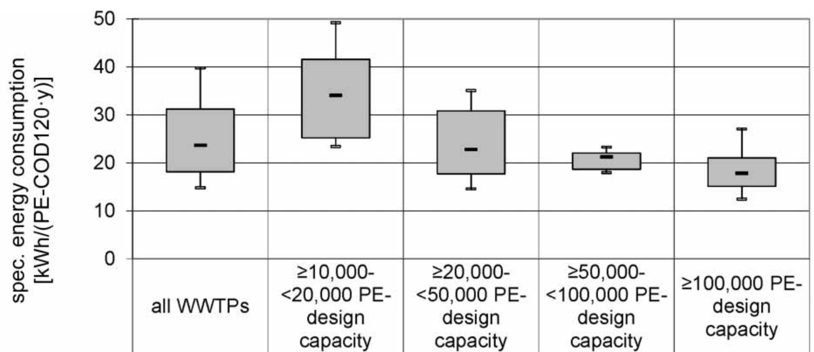
Figure 6 | Distribution of processes of total energy consumption of small and large municipal WWTPs in Austria (data without outliers).

Table 1 shows the specific energy consumption of the investigated WWTPs classified into their type of sludge stabilisation. Each category is further subdivided into the plant size. The table shows that WWTPs with aerobic sludge stabilisation have a higher specific energy consumption (about 6 kWh/(PE-COD120·y)) than WWTPs with mesophilic sludge digestion. This table confirms the dependence of energy consumption on plant size and technology, as also described in literature (Mizuta & Shimada 2010; Krampe 2013).

Figure 5 illustrates the specific energy consumption of the investigated WWTPs. In this figure the WWTPs are subdivided into their type of sludge stabilisation technology. The median of the specific energy consumption of WWTPs with mesophilic sludge digestion amounts to 33 kWh/(PE-COD120·y) and is about 10 kWh/(PE-COD120·y) lower than of WWTPs with aerobic sludge stabilisation.

From the analysis above it can be said that the variation in energy consumption depends mainly on the type of sludge stabilisation, which obviously depends on the size of a treatment plant.

Figure 6 illustrates the energy consumption related to the main and support processes. The figure shows that process 2 (mechanical–biological wastewater treatment) is by far the most relevant process not just with regard to water pollution control, but also with regard to energy consumption. All other main processes (process 1, 3 and 4) are of lower importance regarding energy consumption. The specific energy consumption for sludge thickening and stabilisation contributes just 8% and 12% to the total energy consumption of small and large WWTPs, respectively, because energy consumption



	all WWTPs	≥10,000-<20,000 PE-design capacity	≥20,000-<50,000 PE-design capacity	≥50,000-<100,000 PE-design capacity	≥100,000 PE-design capacity
number	102	24	55	7	16
75th percentile	31.3	41.6	30.8	22.1	21.0
90th percentile	39.8	49.2	35.1	23.3	27.1
10th percentile	14.8	23.4	14.6	18.0	12.4
median	23.7	34.0	22.8	21.2	17.8
25th percentile	18.2	25.2	17.7	18.7	15.1

Figure 7 | Specific energy consumption of process 2 of municipal WWTPs in Austria (data without outliers).

for aerobic sludge stabilisation is allocated to process 2. The support processes (obligatory and optional processes) can be neglected with regard to energy consumption.

Due to the importance regarding energy consumption of process 2 (mechanical–biological wastewater treatment), a more detailed analysis was carried out. Figure 7 shows the specific energy consumption of process 2. The WWTPs are classified into different size groups. The figure shows the size-dependency of the process. The results show that energy optimisation should focus on mechanical–biological wastewater treatment, as it is the most energy-consuming process. For the identification of further optimisation potential splitting of the process (e.g. aeration, mixing) is inevitable.

Energy efficiency

Energy efficiency of WWTPs is of increasing interest, not only due to economic but also due to environmental aspects. Hence, the optimisation of energy consumption and generation in WWTPs is an important topic. Examples for energy self-sufficient WWTPs in Austria are described in Nowak et al. (2011). The examination of the benchmarking data pool shows that three of the investigated large and four of the small WWTPs operate energy self-sufficiently on a yearly basis.

CONCLUSIONS

Based on a dataset of 104 WWTPs, this work analyses operating costs and energy consumption of municipal WWTPs in Austria. From the presented results, the following main conclusions can be drawn:

- Personnel costs are the most important cost element, contributing more than 30% to the total operating costs. Energy costs contribute only 17% and 11% to the total operating costs of small and large WWTPs, respectively.
- Process 4 (further sludge treatment and disposal) shows the highest cost-relevance of all main processes (30% of total operating costs).
- The investigated large WWTPs show a yearly specific energy consumption of about 30 kWh/PE-COD120. In comparison, the specific energy consumption of smaller WWTPs is about 10 kWh/(PE-COD120·y) higher.
- Process 2 (mechanical–biological wastewater treatment) is by far the most important process regarding energy consumption (67% and 60% of total energy consumption of small and large WWTPs, respectively).
- Operating costs and energy consumption decrease with increasing plant size (economy of scale). As the difference in energy consumption is mainly caused by the type of sludge stabilisation, smaller WWTPs with aerobic sludge stabilisation have a much higher specific energy consumption than large WWTPs with mesophilic sludge digestion.
- WWTPs can be operated self-sufficiently on a yearly basis. Prerequisites for this are a small specific energy consumption and a high specific energy production (including digestion of co-substrate).

The results of this work may serve as a basis for international comparisons regarding operating costs and energy consumption of municipal WWTPs of different size groups and hence may help to identify inefficiencies at WWTPs.

REFERENCES

Balmér, P. & Hellström, D. 2012 Performance indicators for wastewater treatment plants. *Water Science and Technology* **65** (7), 1304–1310.

Baumann, P., Maurer, P. & Roth, M. 2014 *Senkung des Stromverbrauchs auf Kläranlagen, Praxisleitfaden (Reduction of the Energy Consumption of WWTPs, Field Manual).* Heft 4, DWA Landesverband Baden-Württemberg, Stuttgart, Germany.

Foladori, P., Vaccari, M. & Vitali, F. 2015 Energy audit in small wastewater treatment plants: methodology, energy consumption indicators, and lessons learned. *Water Science and Technology* **72** (6), 1007–1015.

Haberkern, B., Maier, W. & Schneider, U. 2008 *Steigerung der Energieeffizienz auf kommunalen Kläranlagen (Increasing the Energy Efficiency of WWTPs).* Umweltbundesamt, Dessau-Roßlau, Germany.

Krampe, J. 2013 Energy benchmarking of South Australian WWTPs. *Water Science and Technology* **67** (9), 2059–2066.

Kroiss, H. & Lindtner, S. 2005 Costs and cost-effectiveness analysis for waste water services. In: *Proceedings of IWA Conference on Nutrient Management in Wastewater Treatment, September 2005, Krakow, Poland*, pp. 18–21.

Lindtner, S. 2004 *Beitrag zum Benchmarking von Abwasserreinigungsanlagen (Contribution to WWTP Benchmarking)*. Wiener Mitteilungen 189, Vienna, Austria.

Lindtner, S. & Vohryzka, F. 2015 *Der Energieverbrauch österreichischer Kläranlagen (Energy Consumption of Austrian Wastewater Treatment Plants).* Wiener Mitteilungen 232, Vienna, Austria.

Lindtner, S., Kroiss, H. & Nowak, O. 2004 Benchmarking of municipal waste water treatment plants (an Austrian project). *Water Science and Technology* **50** (7), 265–271.

Lindtner, S., Schaar, H. & Kroiss, H. 2008 Benchmarking of large municipal wastewater treatment plants treating over 100,000 PE in Austria. *Water Science and Technology* **57** (10), 1487–1493.

Mizuta, K. & Shimada, M. 2010 Benchmarking energy consumption in municipal wastewater treatment plants in Japan. *Water Science and Technology* **62** (10), 2256–2262.
Nowak, O., Keil, S. & Fimml, C. 2011 Examples of energy self-sufficient municipal nutrient removal plants. *Water Science and Technology* **64** (1), 1–6.
Quadros, S., Rosa, M. J., Alegre, H. & Silva, C. 2010 A performance indicators system for urban wastewater treatment plants. *Water Science and Technology* **62** (10), 2398–2407.
Svardal, K. & Kroiss, H. 2011 Energy requirements for waste water treatment. *Water Science and Technology* **64** (6), 1355–1361.

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