SMART ENERGY MANAGEMENT
AUDIT CONCEPT: COMBINED AUDIT REPORTS

Development and results from audited wastewater treatment plants in the project IWAMA – Interactive Water Management

IWAMA Interactive Water Management

Interreg Baltic Sea Region

EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND

EU STRATEGY FOR THE BALTIC SEA REGION FLAGSHIP

SMART ENERGY MANAGEMENT AUDIT CONCEPT: COMBINED AUDIT REPORT

The concept of performing energy self audits at wastewater treatment plants in the Baltic Sea Region

The smart energy management audit concept was developed within the INTERREG Baltic Sea Region (BSR) funded Interactive Water Management (IWAMA) project by the Technical University of Berlin. The audit concept was developed and tested in cooperation with wastewater treatment plants (WWTP) in the BSR that were assessed for evaluating the energy management during the municipal wastewater treatment process.

A total of 9 WWTPs took part in the development process: Grevesmühlen WWTP from Germany, Pomorzany and Zdroje WWTPs from Szczecin, Poland, Kaunas WWTP from Lithuania, Daugavpils and Jurmala WWTPs from Latvia and Tartu and Türi WWTPs from Estonia. The aim of the development was to provide a concept to enable operators of WWTP to assess energetical aspects related to the wastewater and sludge treatment. A tool has been programmed using Microsoft Excel and VBA-code. The tool originally developed in English has been translated to Estonian, German, Finnish, Latvian, Lithuanian, Polish, Russian and Swedish languages. A guideline document (Guidelines for using the Smart Energy Management Self Audit Tool) is available with detailed instructions and descriptions of the calculations. Interested WWTP operators and other parties are invited to evaluate their WWTPs without external help needed (through the self-auditing process).

In the auditing process, the energy consumption of the whole treatment plant is analysed. Ideal consumption values are calculated automatically by the tool if required process data is provided. The comparison reveals the saving potential. Based on these findings, the tool includes also general recommendations on optimization measures.

Current report gives a short overview of different parameters evaluated in the energy audits with results from the IWAMA project partners, who participated in the audit development and testing process. The data from the WWTP is displayed anonymously. All WWTP received individual feedback and the finalized audit tool. As the participating WWTPs varied greatly from both size and used technologies (from no sludge treatment up to drying and incineration) not all results are available for every WWTP.

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Editor's note: In this report, a comma is used as decimal marker.

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1 INTRODUCTION

1.1 General background information about energy efficiency in WWT

Wastewater treatment is a complex task in general. Many efforts have been made in the past in order to improve the effluent quality. A main driver in the Baltic Sea Region (BSR) has been the eutrophication caused by high nutrient inputs. Based on the strict HELCOM recommendations, a lot of plants have successfully improved their effluent quality. However, due to the Energy-Nutrient-Nexus, high removal rates require a high energy input for the nitrification/denitrification process.

As Fossil resources are limited, it is necessary to activate the saving potential. Energy production is a large contributor to climate change due to the CO_2-emissions. Besides this very general motivation, simply saving of operational costs is a guide for wastewater treatment plant (WWTP) operators.

Water utilities are typically the largest consumers of energy in municipalities, often accounting for 30-40 % of total energy consumed. Stationary electricity equals 20 to 40 kWh/(PE_{COD}·a), similar figures are reached in terms of heat energy, though this truly depends on the temperature. Additionally, a mobile energy demand can be assumed with 5 to 7,5 kWh/(PE_{BOD5}·a). WWTPs in Germany consume 4,4 TWh/a, which is considerably more electricity than all schools [SCHRÖDER AND SCHRENK, 2008]. Increasing energy costs emphasize the effects of energy efficiency measures on reduction of operating costs. Still, smart energy management is not commonly applied. Concluded from experiences at previous energy optimizations of WWTP in Germany predicting a 15-30% potential to save energy while simultaneously keeping or even improving the nutrient removal efficiency seems to be realistic. A 5-10 % higher degree of efficiency can be achieved by improved control. For WWTP in the BSR the requirement to save energy is much more difficult than for others because of the strict nutrient effluent demands. It should be noted that besides reflections about energy efficiency and production hygienic aspects and nutrient removal are still the main tasks of wastewater treatment sector.

1.2 Energy efficient wastewater treatment

Energy efficient wastewater treatment is influenced by a lot of factors. For instance, the consumption of electrical energy depends on the size of the treatment plant. Larger treatment plants usually show a better performance in comparison to the connected inhabitants (Figure 1).

Energy optimization needs looking at each specific sewage treatment plant. Without question, the biological treatment is the most important consumer. Also, there is lots of options to optimize, because the energy demand of the aeration depends on many factors:

- Efficiency of the aeration system
    - Kind and age of aerators (surface; membranes)
    - Oxygen transfer capacity
    - Air compression, distribution and input system
    - Control of the aeration (actual O_2-control value)
- Wastewater
    - Composition of the sewage (C/N-ratio)
    - Temperature of the sewage
    - Purification efficiency of the plant
- Technology and operation
    - Geometry of the activation tank
    - Technology (e.g. COD-elimination in pre-settler)
    - Dry-solid content in the activation tank
    - Sludge age

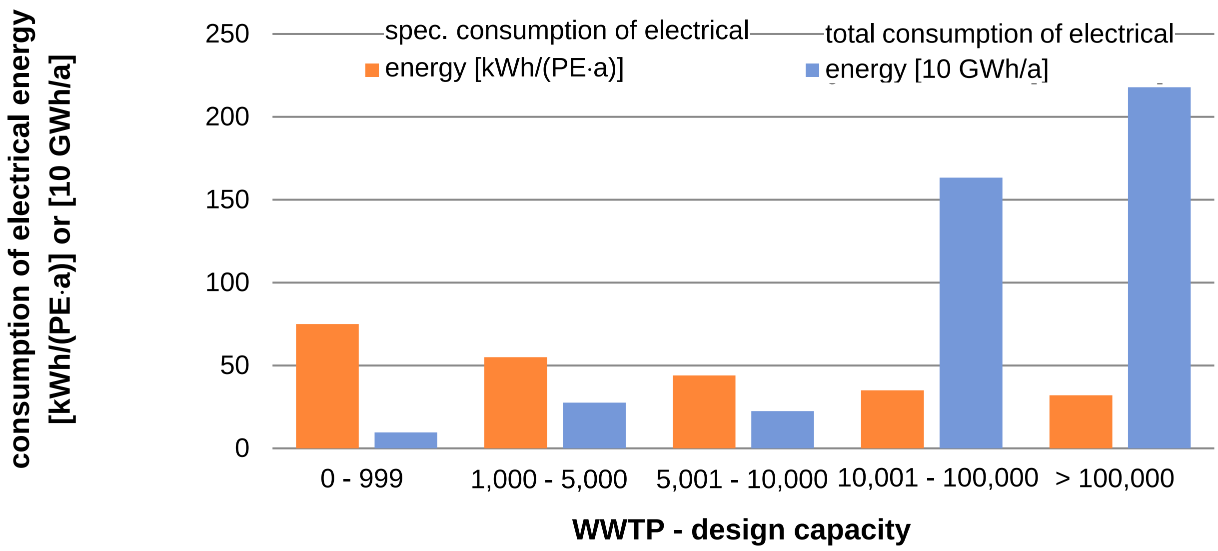


Figure 1 - Comparison of specific electrical energy consumption in relation to the size of the WWTP in Germany, [Haberkern et al., 2008, modified]

Beneath optimizations on the consumption side, it is also advisable to look at energy production. Reducing the consumption of external energy by generation of energy during the treatment process is possible by either electrical or thermal energy production. Else it is also feasible to apply heat recovery wherever possible. Small waterpower units have been successfully applied. And since often space is not a limiting factor on the property of the WWTP, solar or wind power could also be installed.

The energy potential in sewage and sludge has been analyzed. The COD-energy equivalent is set with 14 kJ/g COD or 3.89 Wh/g COD. Assuming 120 g COD/PE·d), raw sewage contains 0.47 kWh/(PE·d). The energy potential in sludge:

- raw sludge < 20 W/E
- stabilized sludge :> 6 W/E = 0.15 kW/ (E · d)
- in biogas ~ 10 W/E ~ 48 kW/ (E · a)
  (incl. primary sludge)

Also heat energy can be used. At 17° C sewage contains over 100 W/PE.

In Germany, 1.385 GWh of electrical energy have been produced from biogas at WWTP in the year 2015. With this amount a city like Frankfurt/Main could be served for one year, assuming an average consumption of 1,800 kWh per capita. Almost the total amount has been used for self-supply, only 8% have been sent to the grid. Compared with other renewable energy sources, biogas production at WWTP has only a minor share of about 1%. Out of 10,000 WWTP 1,252 have produced biogas via anaerobic sludge treatment. [Statistisches Bundesamt, 2016] If also smaller plants are taken into account, the potential would even grow. Additional measures like co-fermentation also lead to a higher potential. But it has to be mentioned that the economic feasibility has to be proven individually.

The current report presents in brief the smart audit concept and selected results from audits performed at 9 WWTP as part of the project Interactive Water Management (IWAMA) co-funded by the Intereg Baltic Sea Region.

2 AUDIT PROCEDURE

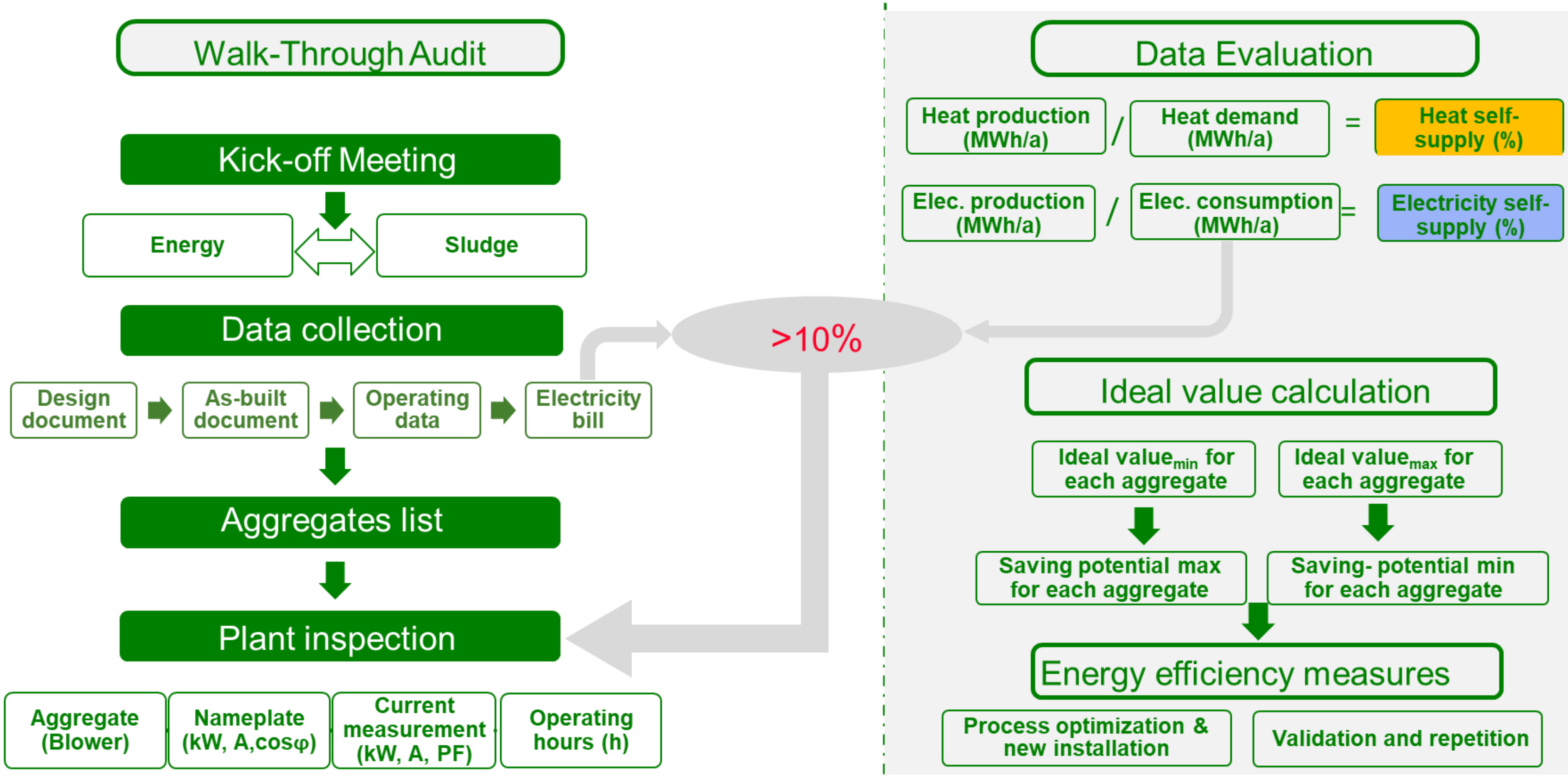


Figure 2 - Walk-through audit process

The decision to perform an energy audit might be supported by regular calculation of energy key figures and comparison with the data obtained from 66 WWTP in the BSR as presented in the key figure report. The detailed energy audit provides necessary information for the suggestion of measures. Better understanding of the process can be followed by implementing process- and technology based measures. Auditing is usually a task carried out by external consultants with experiences of several energy analysis performed. Both data collection and evaluation require intensive labour phases. On the other hand, the operators do have the detailed knowledge about their treatment process. The developed self audit tool shall enable operators to perform energy audits with their own staff resources. Else it is also supposed to be a useful tool for external auditors.

The audit concept is illustrated in Figure 1. The first step of the audit is a detailed data collection. All employees involved in the auditing procedure should meet in Kick off meeting, where the main goals of the audit are explained, individual tasks defined and the evaluation procedure is explained. The main energy consumers have to be detected and listed. If recordings from energy meters exist, this information can be used. Else it is recommendable to include energy measurements of main aggregates (blowers, pumps) in the data collection process. Optional the energy consumption might also be calculated based on recorded/assumed operational hours (Figure 2). To check whether enough data has been considered, a comparison to the annual energy bill of the WWTP is a suitable test. Due to several uncertainties in the data collection, a small deviation is acceptable.

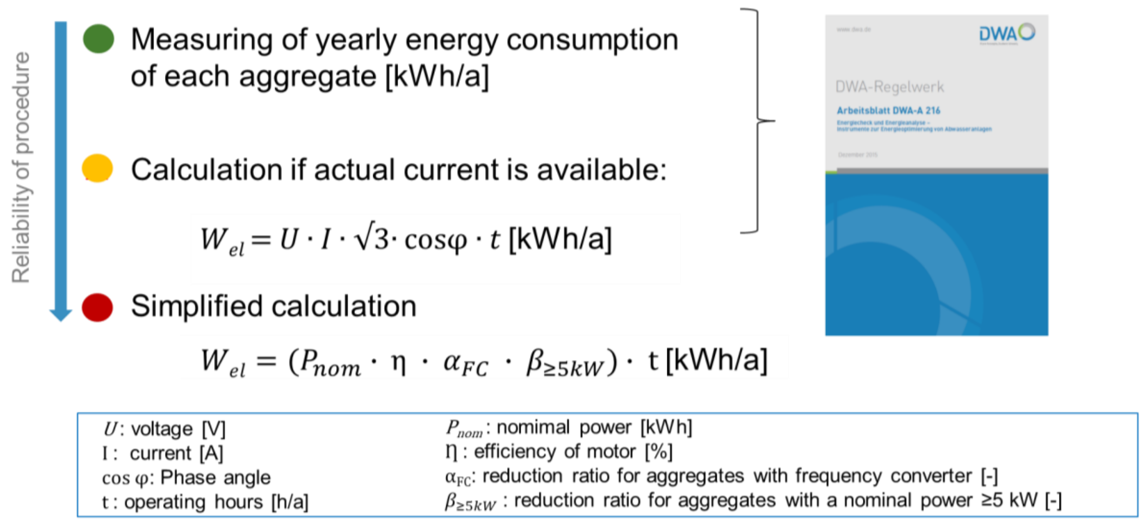


Figure 3 - Options to assess electrical energy consumption

While a lot of data might be available from manuals, as-built-drawings or the process control, it is recommended to verify the list of consumers with a detailed plant inspection.

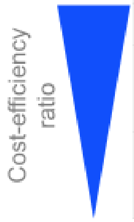
During the project, the data collection at the 9 partner WWTP has been performed together with an international student audit group. Once trained, the students performed the plant inspections and set up the lists of consumers. It was considered a beneficial experience both for the students as well for the guiding operators.

2.1.1 Data evaluation

The proposed audit procedure is based on the guideline DWA-A 216 (2015) and the NRW handbook Energy efficient wastewater treatment (2018). Energy consumption is evaluated based on the COD-load treated.

Due to individual characteristic regarding wastewater composition, design and operation of WWTPs it is recommended to calculate ideal values on an individualized basis. The specific values are derived from a large database or modelling approaches. Varying additional information about the wastewater composition, volumes and local constraints is needed. The main equations used in the IWAMA audit concept are listed in the guideline document.

After successful evaluation procedure the theoretical achievable improvement potentials become obvious. It has to be noted that not in every case they are achievable in practical operation. Best practice examples and guideline documents reveal how the energy efficiency can be improved in detail, be it reducing the consumption or increasing the production onsite. Of course, the measures should be economically feasible. It has to be distinguished between immediate measures such as optimization of process control, short term measures such as replacement of a motor or aggregate at the end of its lifespan and related measures which include major constructional changes in the process (Figure 3). The cost efficiency ratio usually decreases with the complexity of the selected measure.



Classification	Example
Immediate measures	➡ Adjustment of a set point
Short term measures	➡ Adjustment of control, ➡ Replacement of individual aggregates
Related measures	➡ Change of treatment process ➡ investments in additional process technology

Figure 4 - Classification of optimization measures

3 SMART ENERGY MANAGEMENT AUDIT TOOL

The key part of the smart energy audit concept is the energy audit tool. The excel based tool contains internal calculations based on VBA-code. It is available for offline use. The structure is described in table 1.

Table 1 – Structure of the smart energy management self audit tool

Sheet	Function
Disclaimer	- general information
Manual	- short instructions on using the tool
Symbols & Abbreviations	- explanation of symbols and abbreviations
Data input	- choice of existing operational processes and plant components - determining amounts of aggregates to be listed as consumers - collection of relevant parameters to calculate plant related ideal values
List of consumers	- calculation of aggregate-specific and total annual electricity consumption - comparison of calculated and real electricity consumption
Evaluation	- comparison of calculated electricity consumption and plant related ideal values - indicating saving potentials - evaluation of cogeneration plant from electrical point of view
Evaluation | Graph 1	- visualisation of saving potentials of four main treatment stages
Evaluation | Graph 2	- visualisation of saving potentials of all existing process steps
Heat balance	- overview of heat consumption and production - evaluation of cogeneration plant from thermal point of view
Key figures	- brief energy check - comparison of plant related key figures with medians of Baltic Sea Region
Optimization	- general hints and suggestions to develop specific optimization measures
Attachments	- database for background calculations, informative

Apart from English it is possible to select localizations (Estonian, German, Finnish, Latvian, Lithuanian, Polish, Russian, Swedish). The original text is replaced by localizations or translations are displayed next to the English text.

Data input (Figure 4) is organized based on the selected process applied at the audited plant, non-relevant fields remain shadowed.

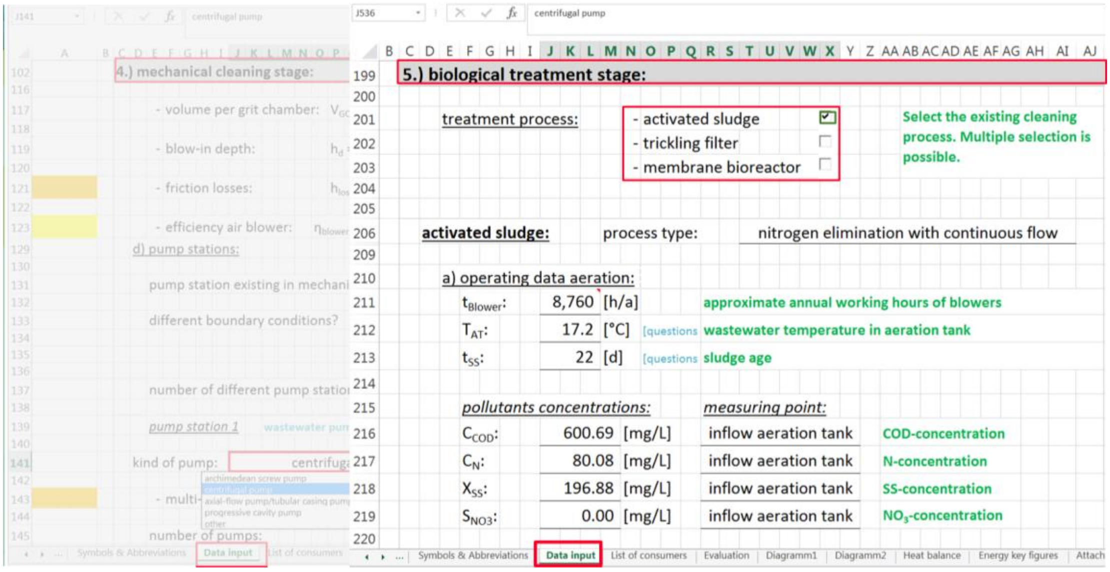


Figure 5 - Example of Data input sheet

The audit concept for smart energy management enables operators of WWTP to detect optimization potentials, mainly in terms of reduced energy consumption or increased onsite energy production. The current situation compared to ideal values for the respective WWTP is displayed in certain user friendly graphs and tables. Based on the findings, the tool includes general suggestions for optimizations to be considered.

4 RESULTS OBTAINED AT AUDITED WWTPS

The smart energy audit concept was developed and tested together with 9 WWTPs from the Baltic Sea Region. The main characteristics of the WWTPs are listed in Table 2. The WWTPs represent a wide range from small to large plants. In the biological stage all treatment plants have established denitrification and biological phosphorus removal. In terms of sludge treatment and processing the individual layouts are different. While some WWTPs do not treat the dewatered sludge any further, other have established additional treatment steps up to onsite sludge incineration.

Table 2 - Main characteristics of the audited WWTPs (reference year 2016)

WWTP	Size [$PE_{COD,120}$]	Feed pumps incl.	Mechanical treatment	Biological treatment	Sludge treatment	Special characteristics
Daugavpils, LV	105 000		S, G	DN, Bio-P	C	No primary settlers
Gdansk-Wschod, PL	896 000		S, G, P	DN, Bio-P	C Dig, Dry, I	
Grevesmühlen, DE	41 000		S, G, P	DN, Bio-P	C, CoDig	Industrial influence Centralized sludge treatment, Deammonification
Jurmala, LV	24 000		S, G	DN, Bio-P	C, Extended aeration	No primary settlers
Kaunas, LT	387 000		S, G, P	DN, Bio-P	C, Dig, Dry	Intermittent DN, Carbon source
Tartu, EE	81 000	X	S, G, P	DN, Bio-P	C, CoDig,	Discfilter, Deammonification
Türi, EE	(9 438)	X	S, G, P	DN, Bio-P	C	Humification, Low data availability
Szczecin-Pomorzany, PL	359 000		S, G, P	DN, Bio-P	CoDig, Dry, I	Dewatering with traveling screen press
Szczecin-Zdroje, PL	120 000	X	S, G, P	DN, Bio-P	CoDig, Dry	

S = Screen, G = Grid removal, P = Primary settler, DN = Denitrification, C = Centrifuge, Dig = Digestion, Dry = Sludge drying, I = Incineration

All plants are compared based with key figures described in the previous report. Figure 6 illustrates the specific energy consumption in kWh/($PE_{COD,120}$ · a). The benchmark of 23 kWh/($PE_{COD,120}$ · a) represents the value which is achieved by the best 20% out of 66 WWTP. Among the results of the 9 audited WWTPs, a large variance is obvious. Very high specific values are usually detected if feed pump stations are included in the WWTP. One third of the audited WWTP already meet the proposed benchmark and only 2 WWTP show unexpectedly high values. The inclusion of feed pump stations does explain the high values to a certain extent, but further checks were necessary. Since the very high specific values also correspond with high specific values for the energy demand of the biological treatment (e_{aer}), already these key figures indicate the optimization potential.

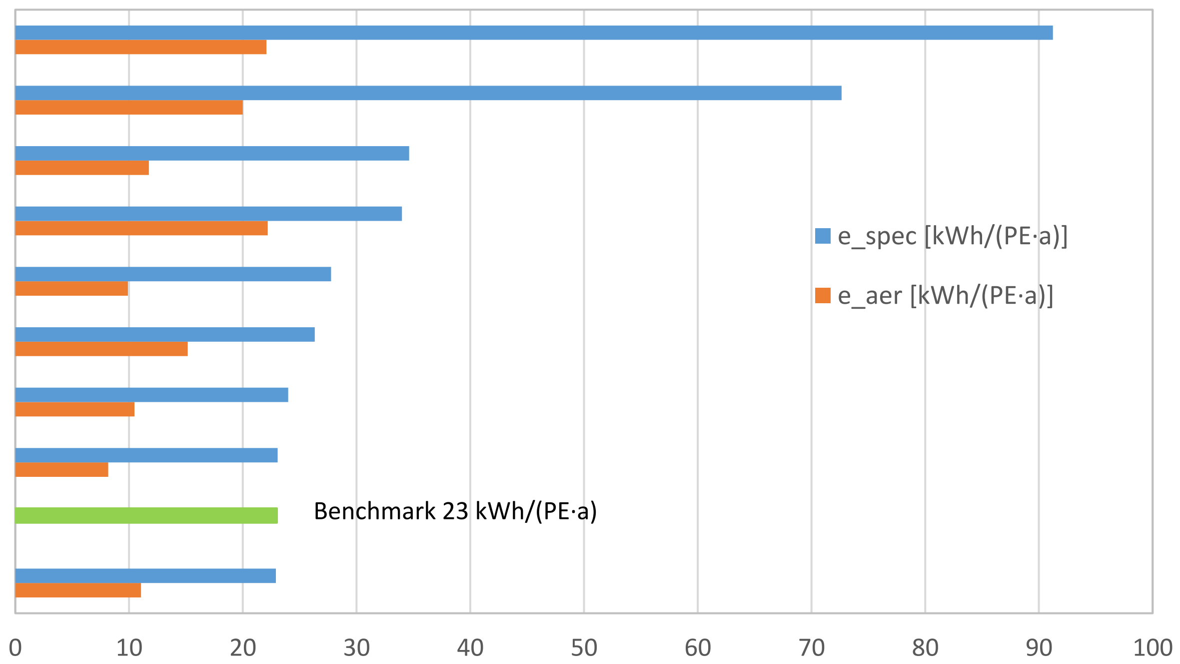


Figure 6 - Specific energy consumption of audit WWPT [total and Aeration]

The first result displayed in the energy audit tool is based on the detailed inventory of electrical devices at the audited WWTP. The share of energy consumed by the treatment steps is visualized for each WWTP in a pie chart (Figure 7 and Annex A.1). The highest share is assigned to the biological treatment, ranging from 42 % – 74 %. These are typical ranges compared to other values reported in literature.

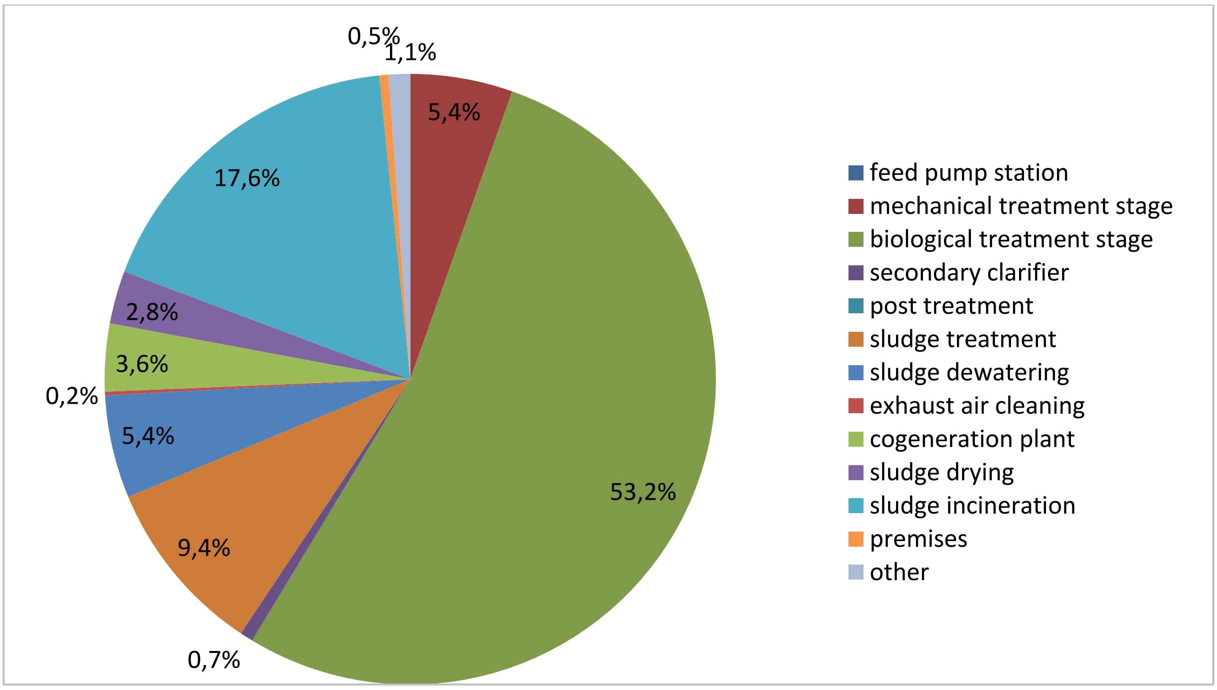


Figure 7 - Share of treatment steps

4.1 Saving potential

Based on the individual situation of the WWTP and characteristic specific values for low energy consumption, the saving potential of the WWTP is displayed both in total and in detail, narrowed down to specific groups of aggregates. Even if a WWTP has obtained very good results in a key figure check, often the detailed analysis reveals optimization potentials. The comparison of the total electricity consumption with the sum of the ideal values revealed in 4 cases a minor saving potential, since the actual value is already in the range between minimum and maximum ideal value. The maximum saving potential shown in Figure 8 is 16 % only, but in theoretically this represents a total sum of 1 470 483 kWh/a. Other results are presented in Annex A.2.

With this data it is possible to calculate CO_2-emissions and potential reductions related to electrical energy consumption of the WWTP. The range of CO_2 emission factors in the BSR is 0,070 – 1.207 kg/kWh. With an average of 0,528 kg $C0_2$/kWh the highest saving potential for all plants equals the annual emission of a WWTP with 100 000 PE. It has to be noted, that this calculation is not part of the excel tool yet.

The next Figure 9 shows, which treatment step might need further investigations. As in most cases, the highest saving potential is estimated for the biological treatment stage. But also the mechanical treatment exceeds the minimum ideal values. The audit tool offers a third type of diagramm, highlighting details of the groups of aggregates, e.g. a pumping station or the blowers.

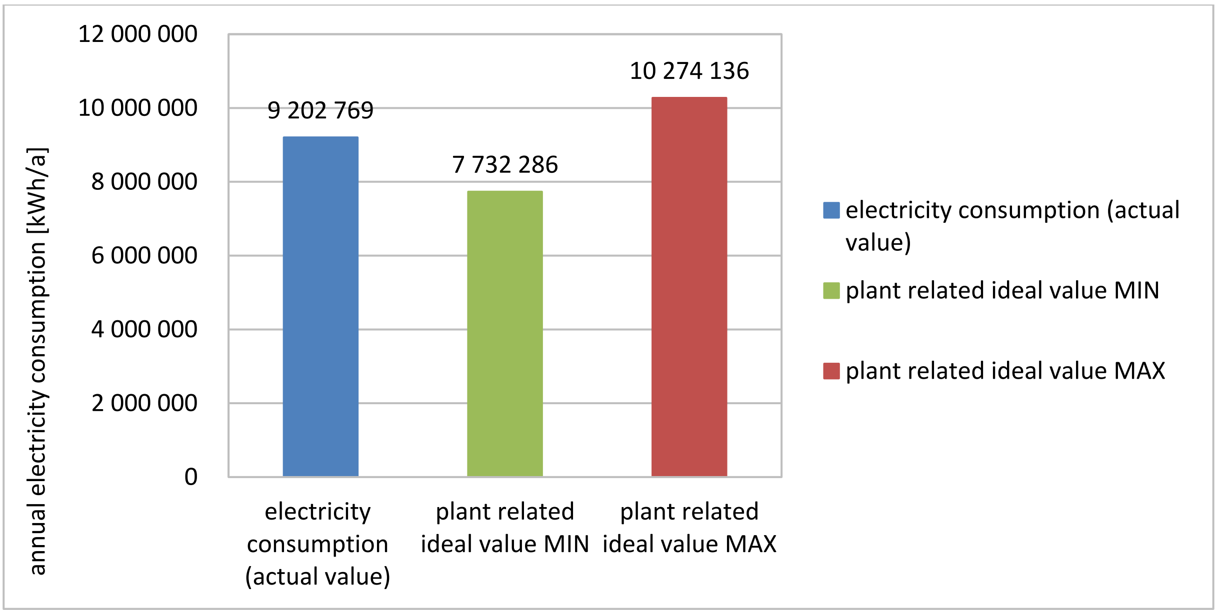


Figure 8 – Actual value and ideal values of the total plant

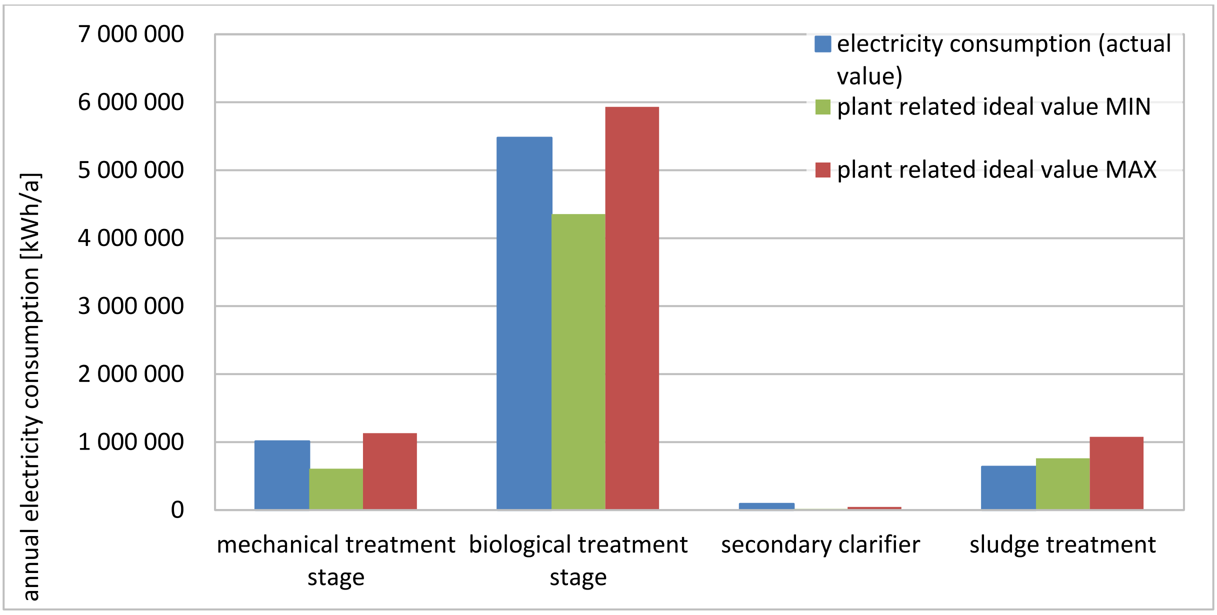


Figure 9 - Total values and ideal values main treatment stages

4.2 Efficiency measures

Based on the evaluated saving potentials, a compilation of general hints and suggestions is displayed here based on the following criteria:

a) if the saving potential is ≥ 5 % of the total electricity consumption

b) if the deviation between actual and ideal value is ≥ 150 %

The compilation is intended to support development of specific optimization measures. Due to varying set-ups of WWTPs specific optimization measures need individual design and calculations.

In the discussions at the audit group meetings it was pointed out by several operators, that they have already started optimization processes. The following measures have been mentioned:

- Replacement of blowers
- Additional digester volume to produce more biogas
- Frequency converters for smarter operation of agitators
- Change of return activated sludge pumps
- Improved removal of floating particles to decrease the energy demand in secondary clarifier
- Accepting co-ferments and treated sludge from other WWTP to increase biogas production

5 CONCLUSION

The smart energy management audit concept developed in the Interreg Baltic Sea region funded project Interactive Water Management (IWAMA) includes a self audit tool for operators to evaluate the energy consumption of a WWTP, an external guideline document and this report.

The tool was developed as excel-file with VBA code, ready for offline use. The tool includes localizations to 9 languages (English, German, Estonian, Finnish, Latvian, Lithuanian, Polish, Russian, Swedish). Feedback from partner WWTPs has been considered in programming phase.

The audits performed at 9 partner WWTPs revealed individual optimization potentials of the treatment processes and equipment. The discussion about interim and final results during audit group meetings have been considered beneficial by all audited WWTPs. The peer group based approach of evaluation offered additional benefits for the partner WWTP, due to the regular international experience exchange.

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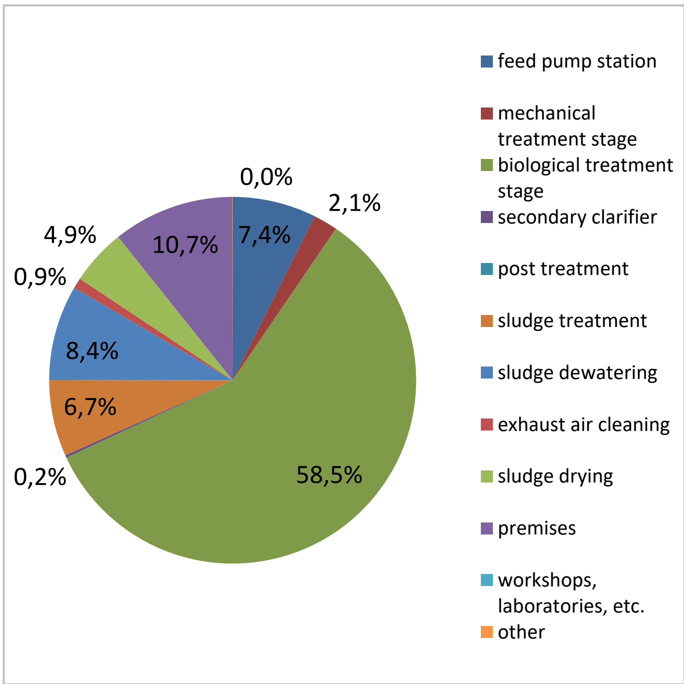
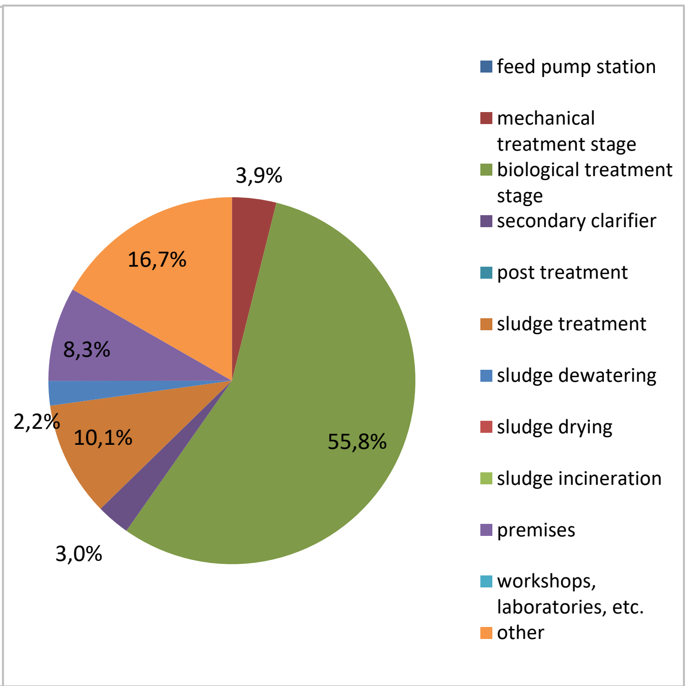
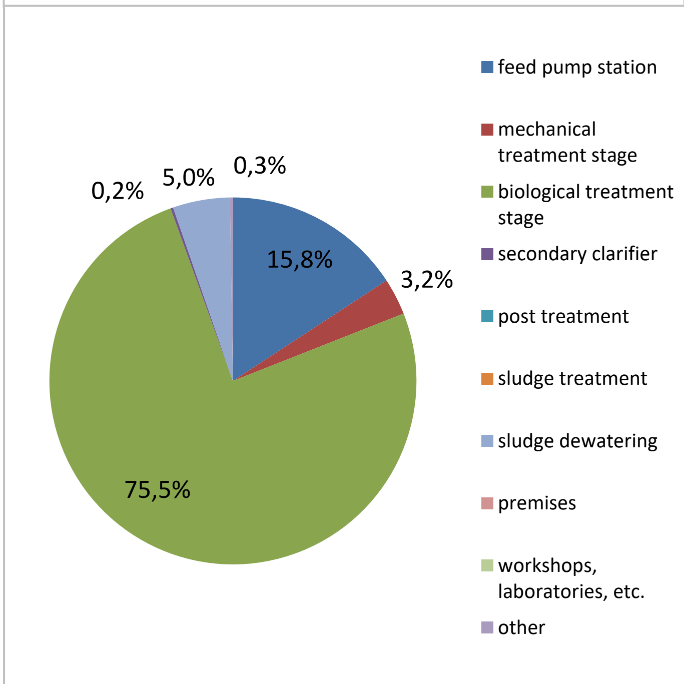
Statistisches Bundesamt 2016 *1395 Gigawattstunden Strom aus Klärgas erzeugt*. Press information 266-16, Wiesbaden.

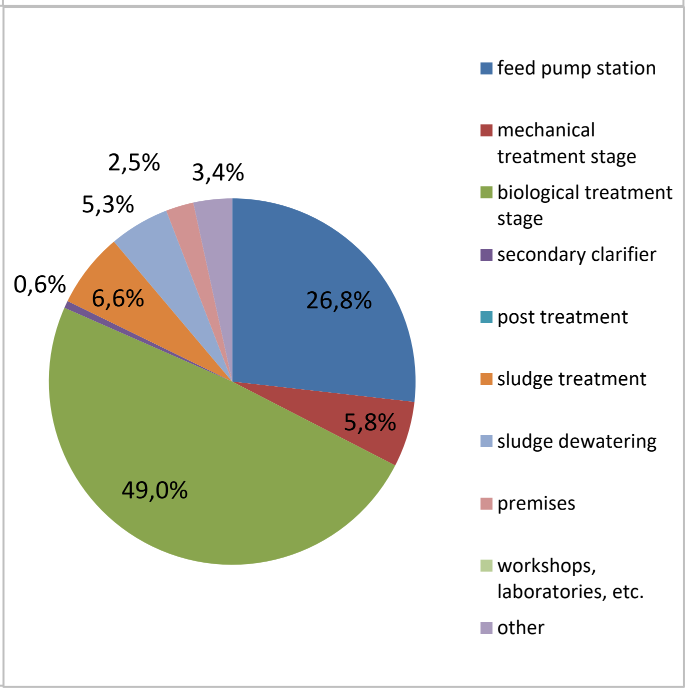
ANNEX

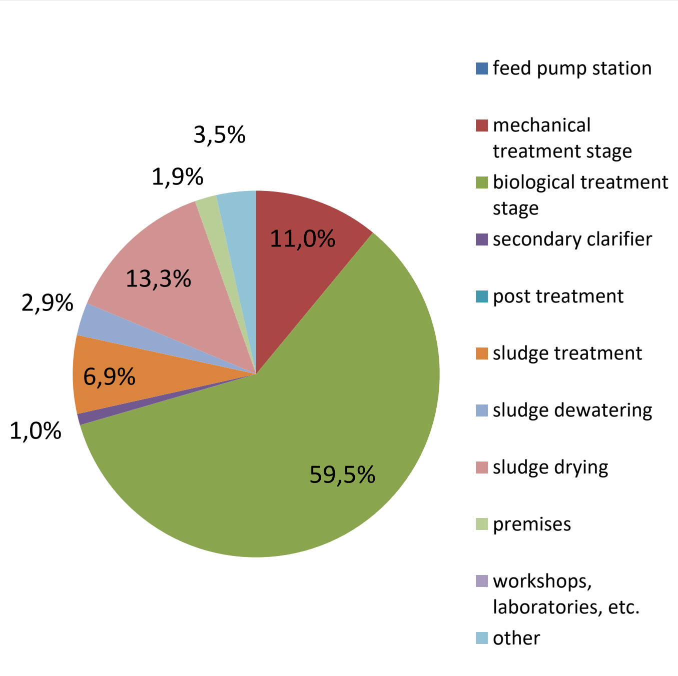
A.1 – Distribution of the electricity consumption on different steps of the process

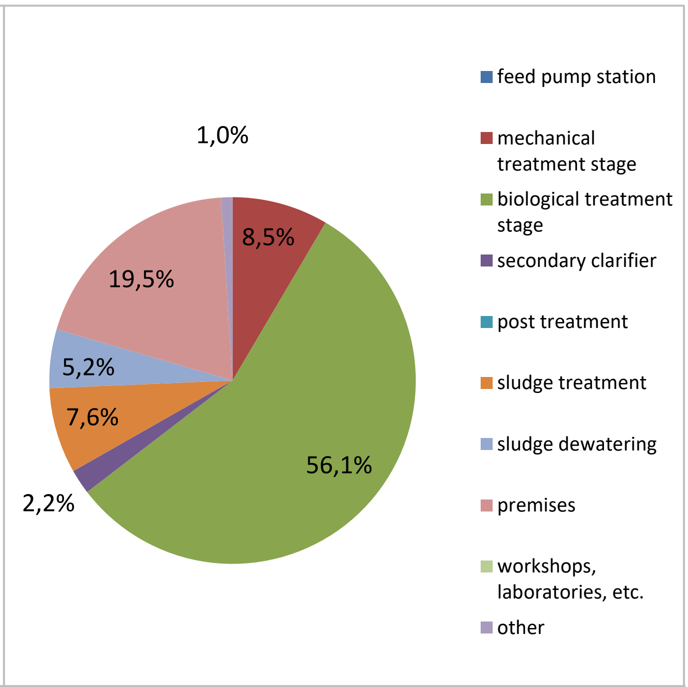









3,5%
1,9%
11,0%
13,3%
2,9%
6,9%
1,0%
59,5%
feed pump station
mechanical treatment stage
biological treatment stage
secondary clarifier
post treatment
sludge treatment
sludge dewatering
sludge drying
premises
workshops, laboratories, etc.
other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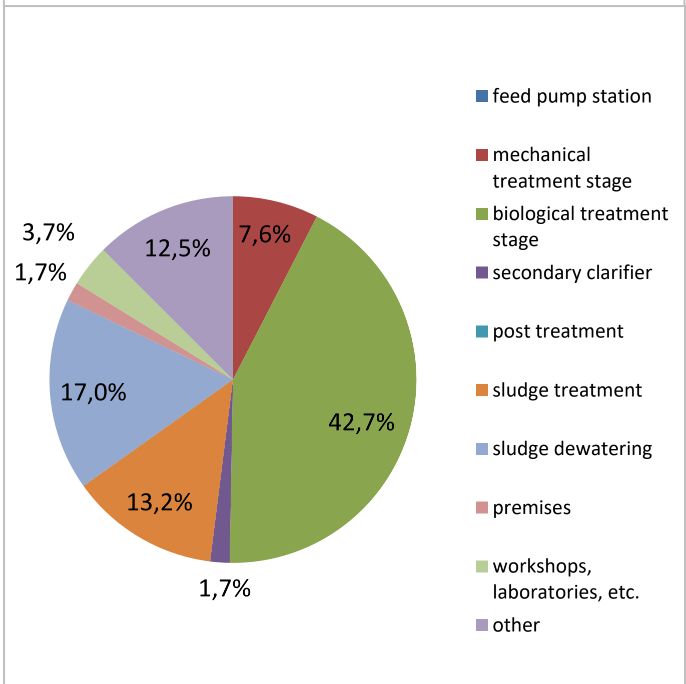
8,5%
19,5%
5,2%
7,6%
2,2%
56,1%
feed pump station
mechanical treatment stage
biological treatment stage
secondary clarifier
post treatment
sludge treatment
sludge dewatering
premises
workshops, laboratories, etc.
other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7,6%
17,0%
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13,2%
1,7%
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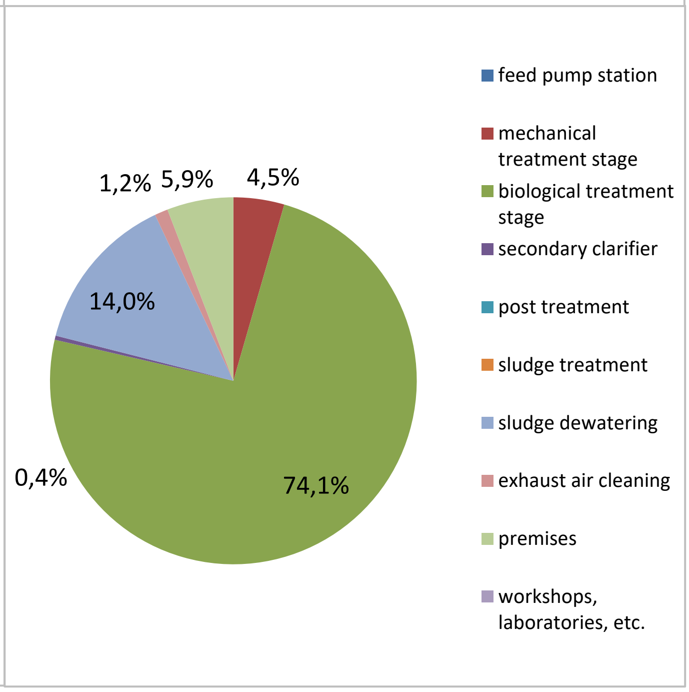
biological treatment stage
secondary clarifier
post treatment
sludge treatment
sludge dewatering
premises
workshops, laboratories, etc.
other


1,2%
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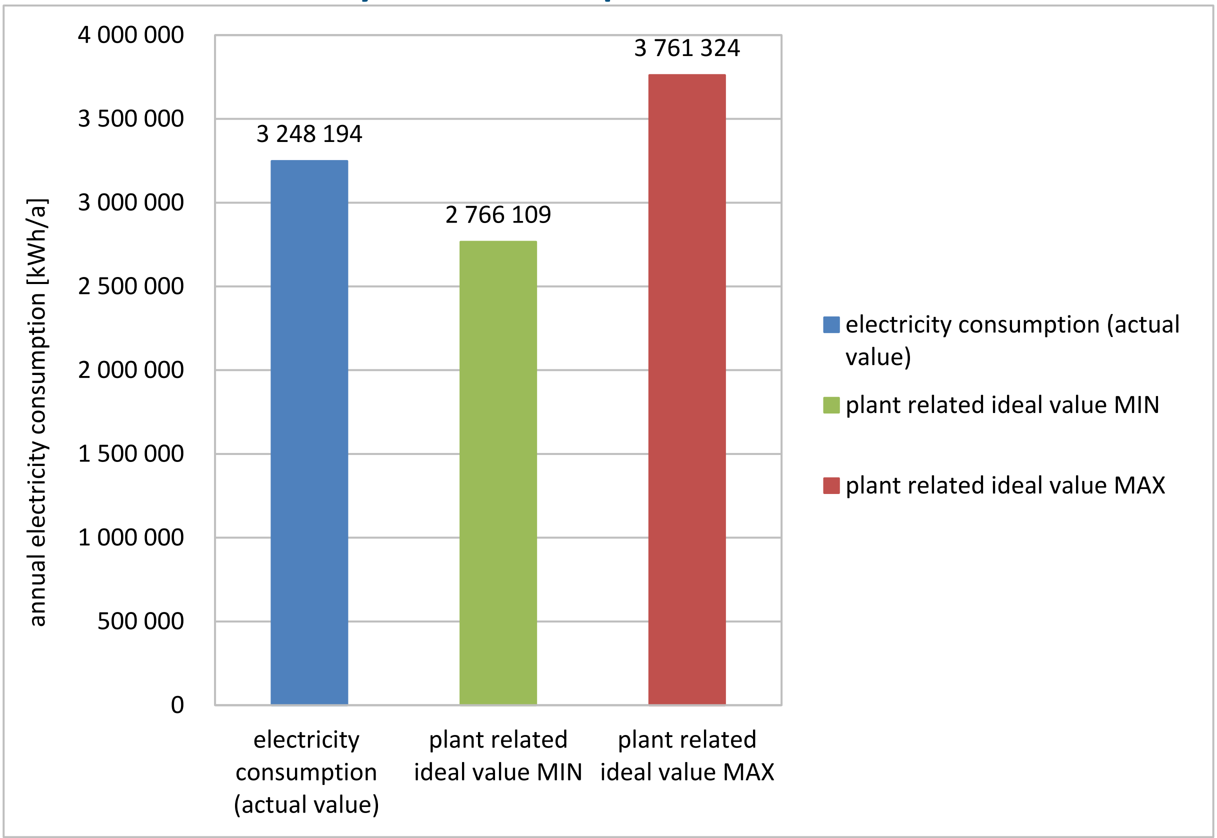
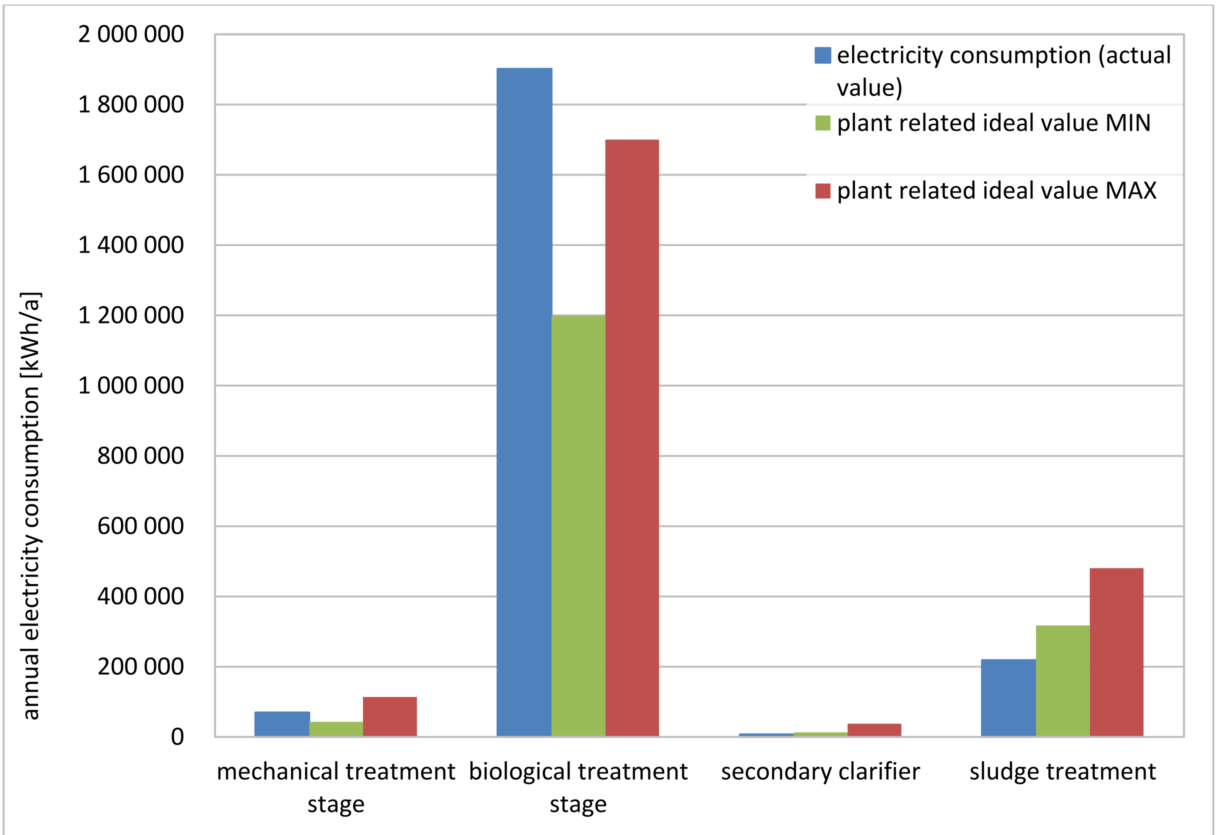
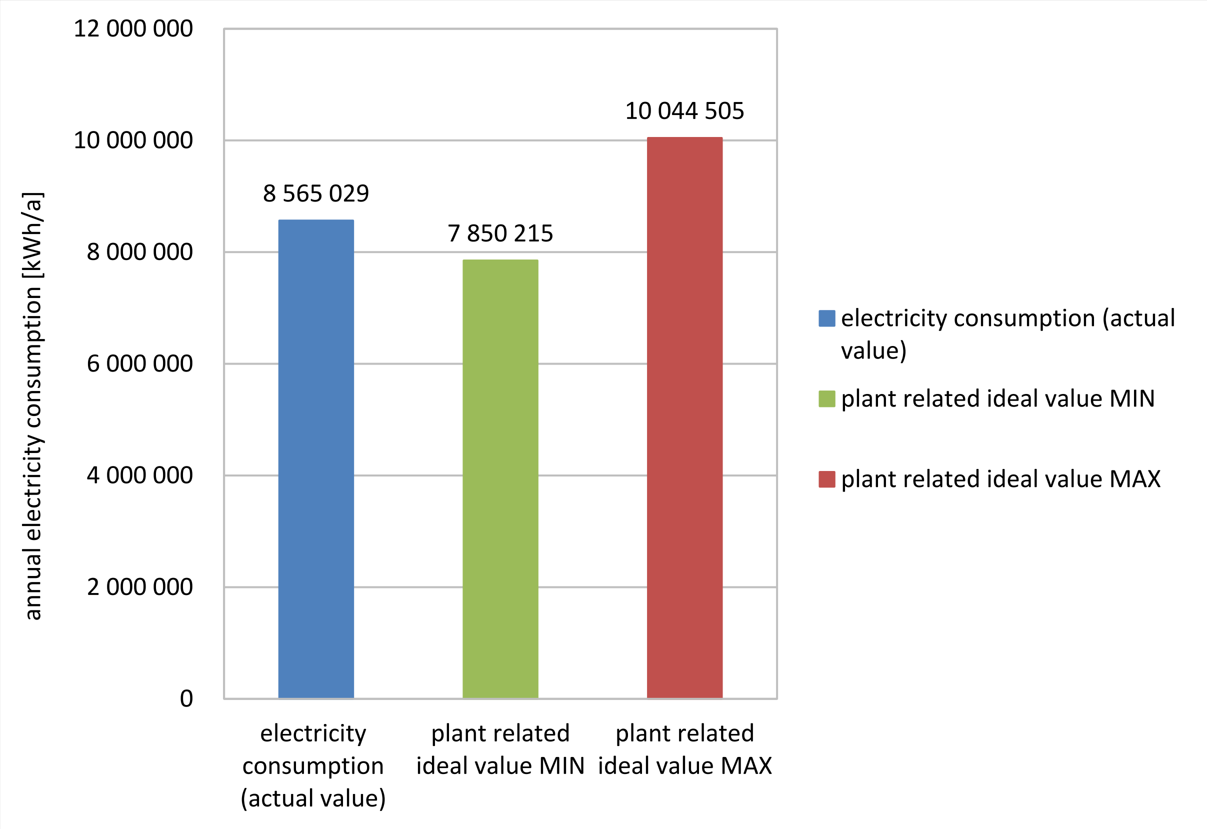
0,4%
74,1%
feed pump station
mechanical treatment stage
biological treatment stage
secondary clarifier
post treatment
sludge treatment
sludge dewatering
exhaust air cleaning
premises
workshops, laboratories, etc.

A.2 – Actual electricity demand and plant related ideal values



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10 000 000
8 000 000
6 000 000
4 000 000
2 000 000
0
annual electricity consumption [kWh/a]
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7 850 215
10 044 505
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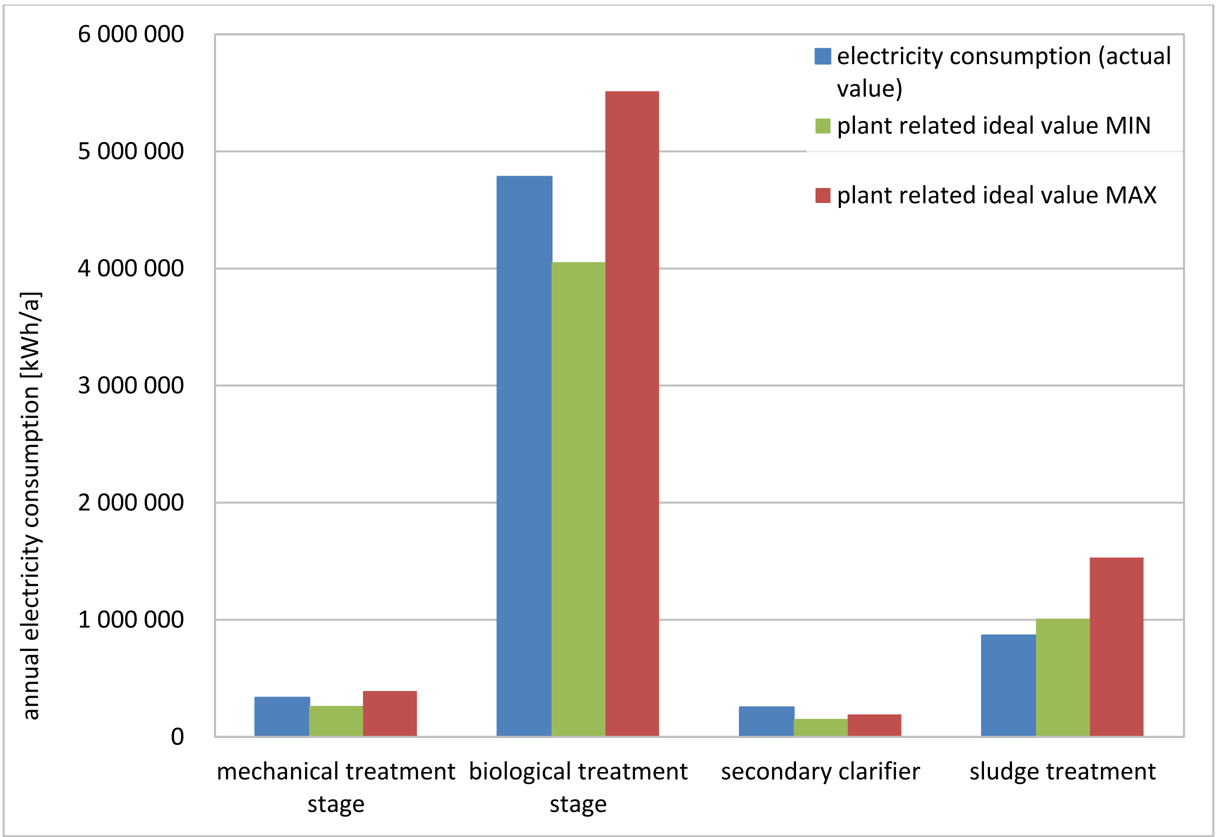
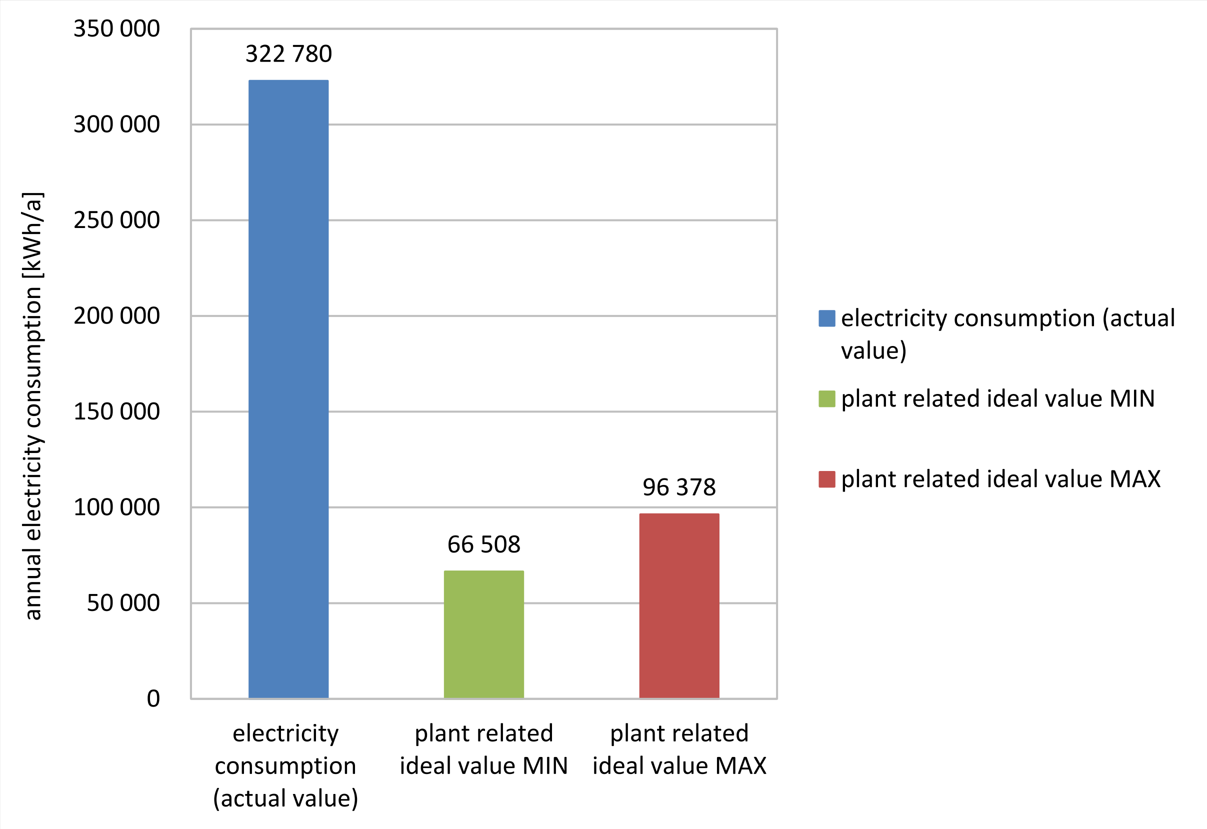
plant related ideal value MIN
plant related ideal value MAX
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX


6 000 000
5 000 000
4 000 000
3 000 000
2 000 000
1 000 000
0
annual electricity consumption [kWh/a]
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX
mechanical treatment stage
biological treatment stage
secondary clarifier
sludge treatment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300 000
250 000
200 000
150 000
100 000
50 000
0
annual electricity consumption [kWh/a]
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66 508
96 378
electricity consumption (actual value)
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plant related ideal value MAX
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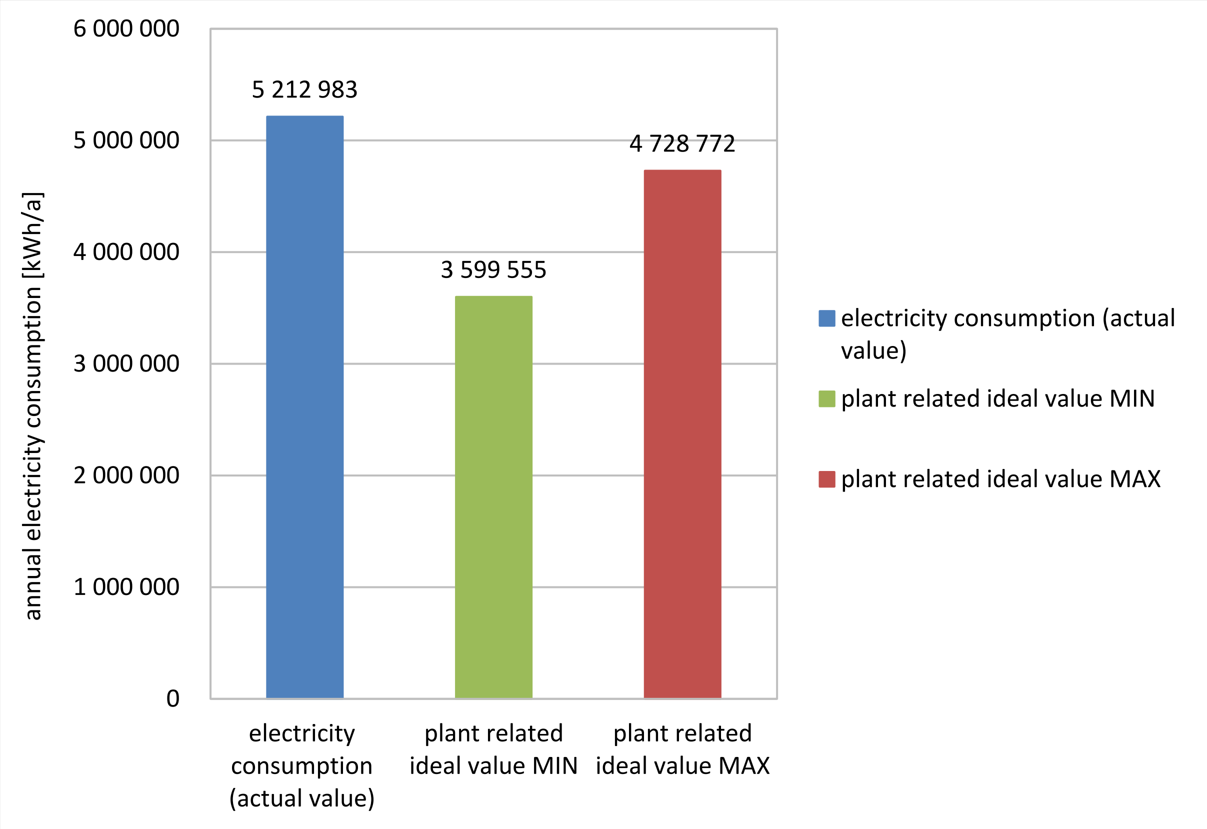
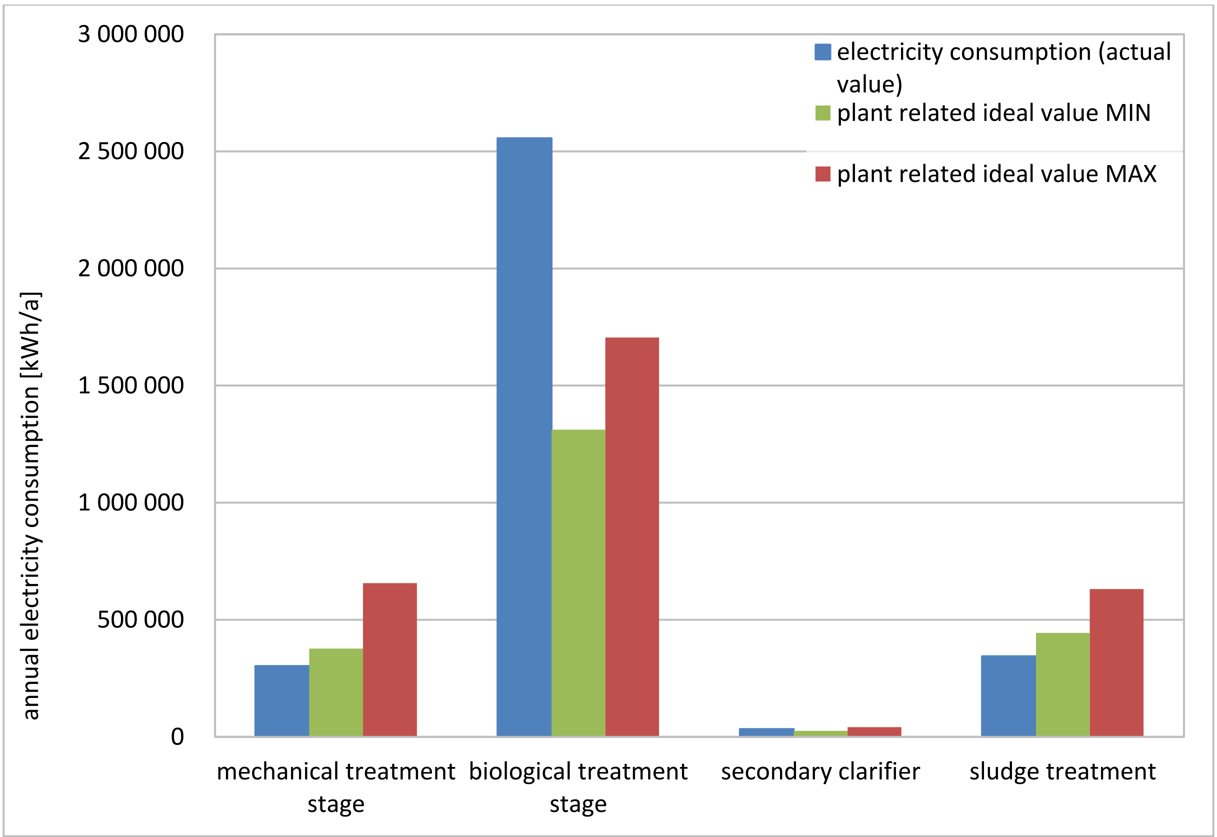
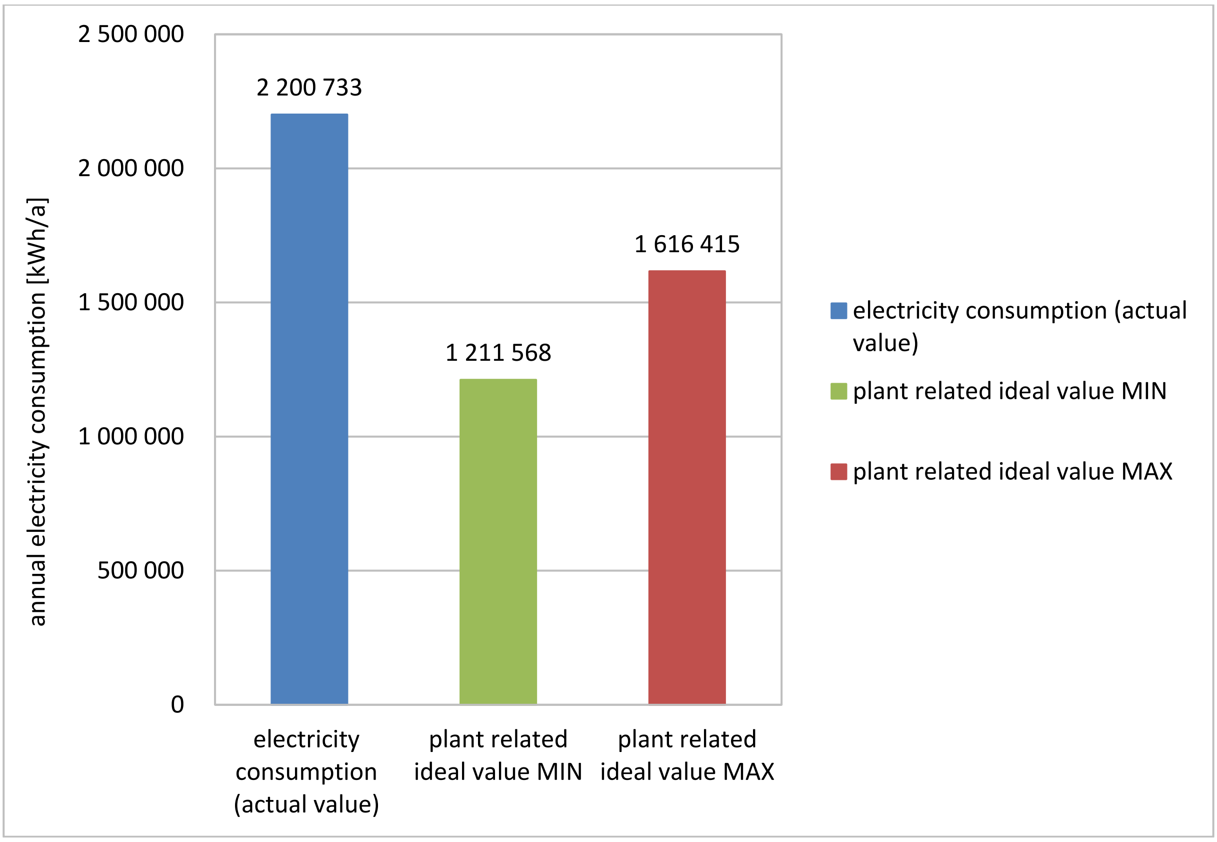
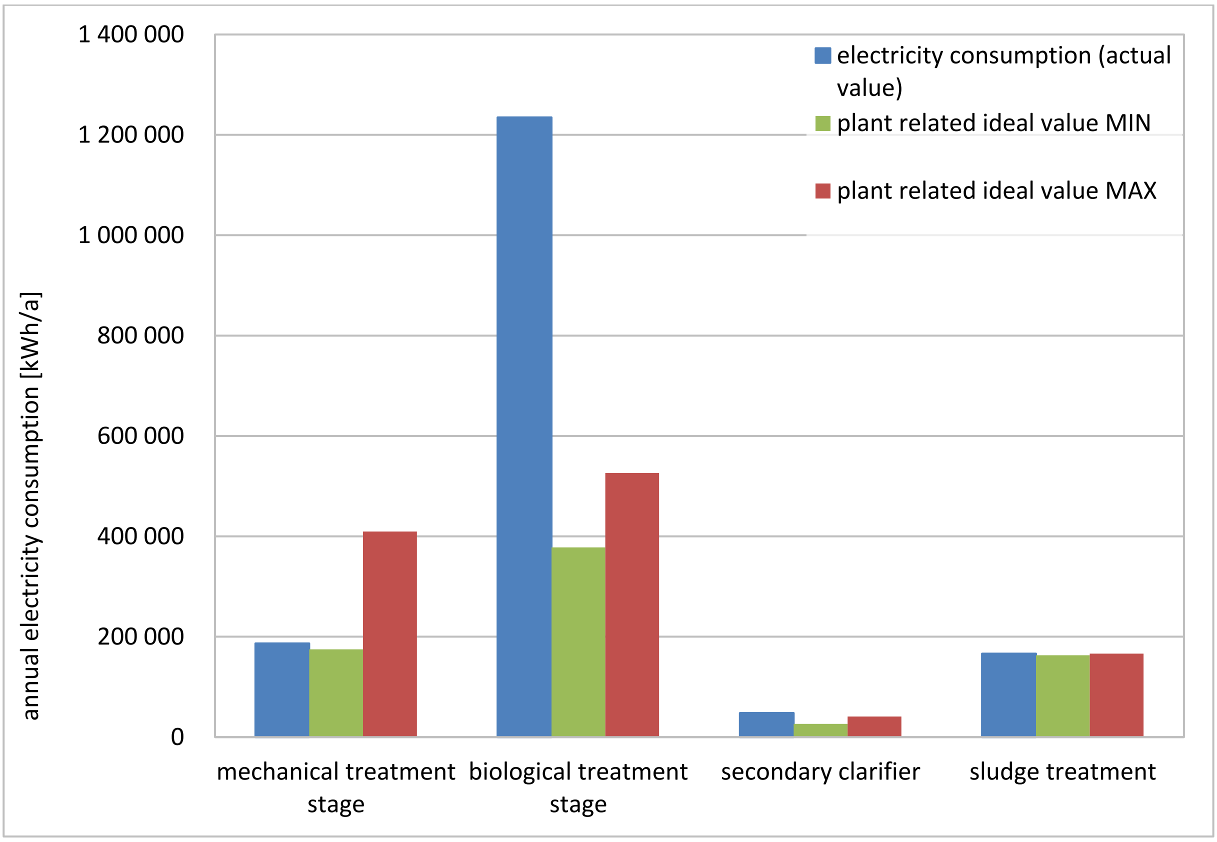
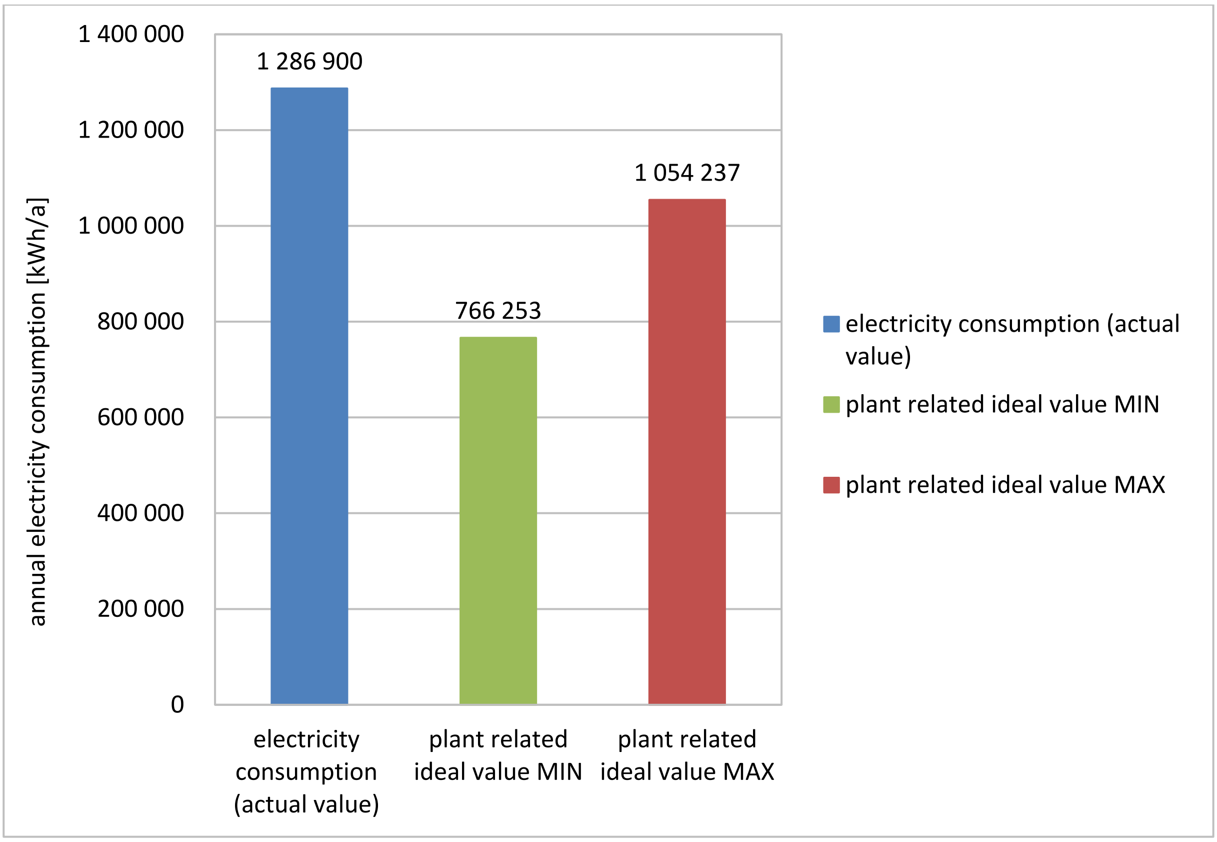
plant related ideal value MIN
plant related ideal value MAX

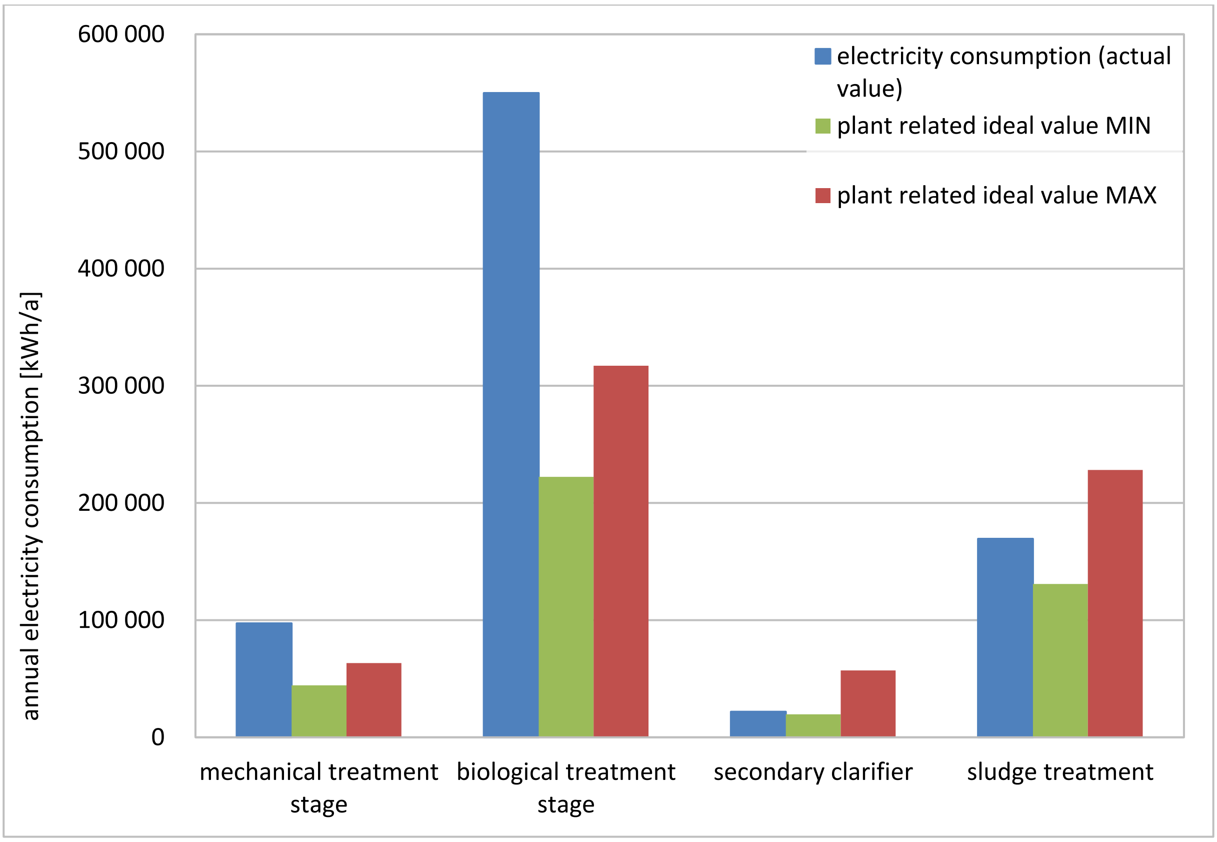

6 000 000
5 000 000
4 000 000
3 000 000
2 000 000
1 000 000
0
annual electricity consumption [kWh/a]
5 212 983
3 599 555
4 728 772
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX

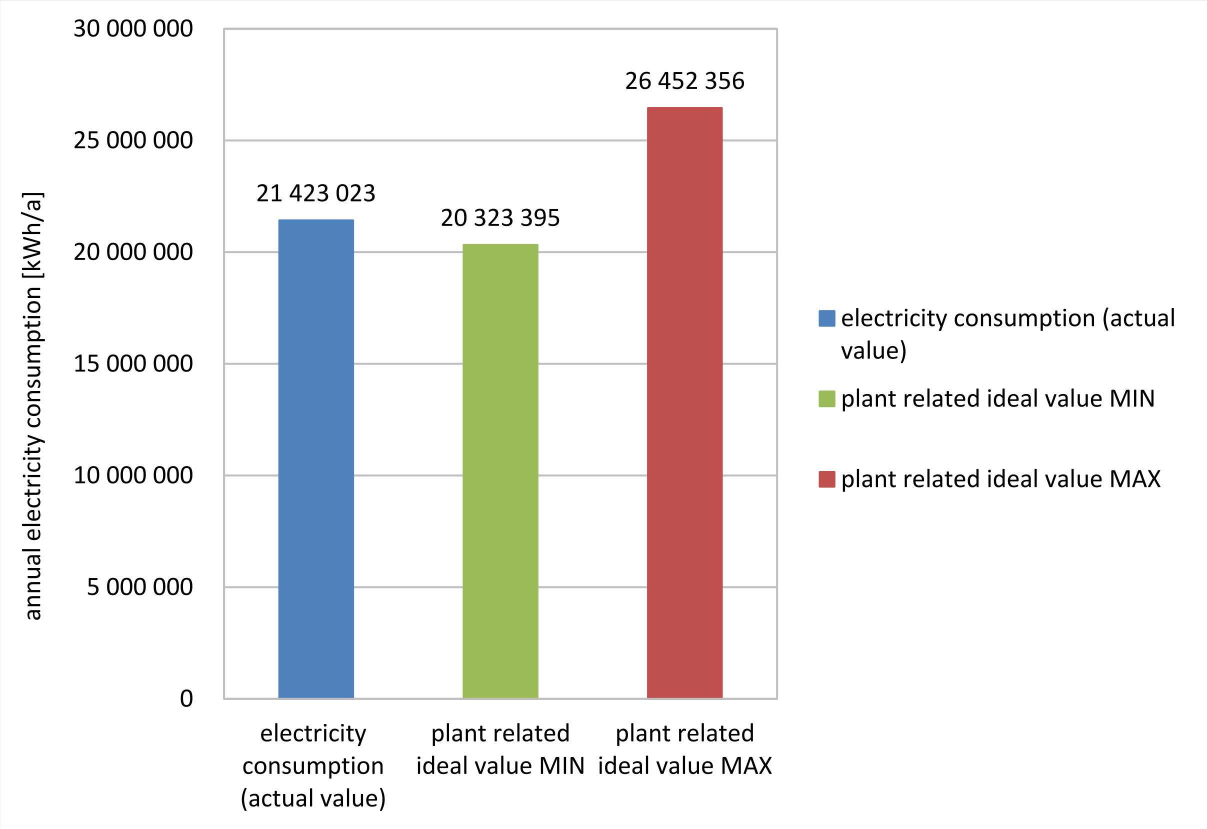

3 000 000
2 500 000
2 000 000
1 500 000
1 000 000
500 000
0
annual electricity consumption [kWh/a]
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX
mechanical treatment stage
biological treatment stage
secondary clarifier
sludge treatment

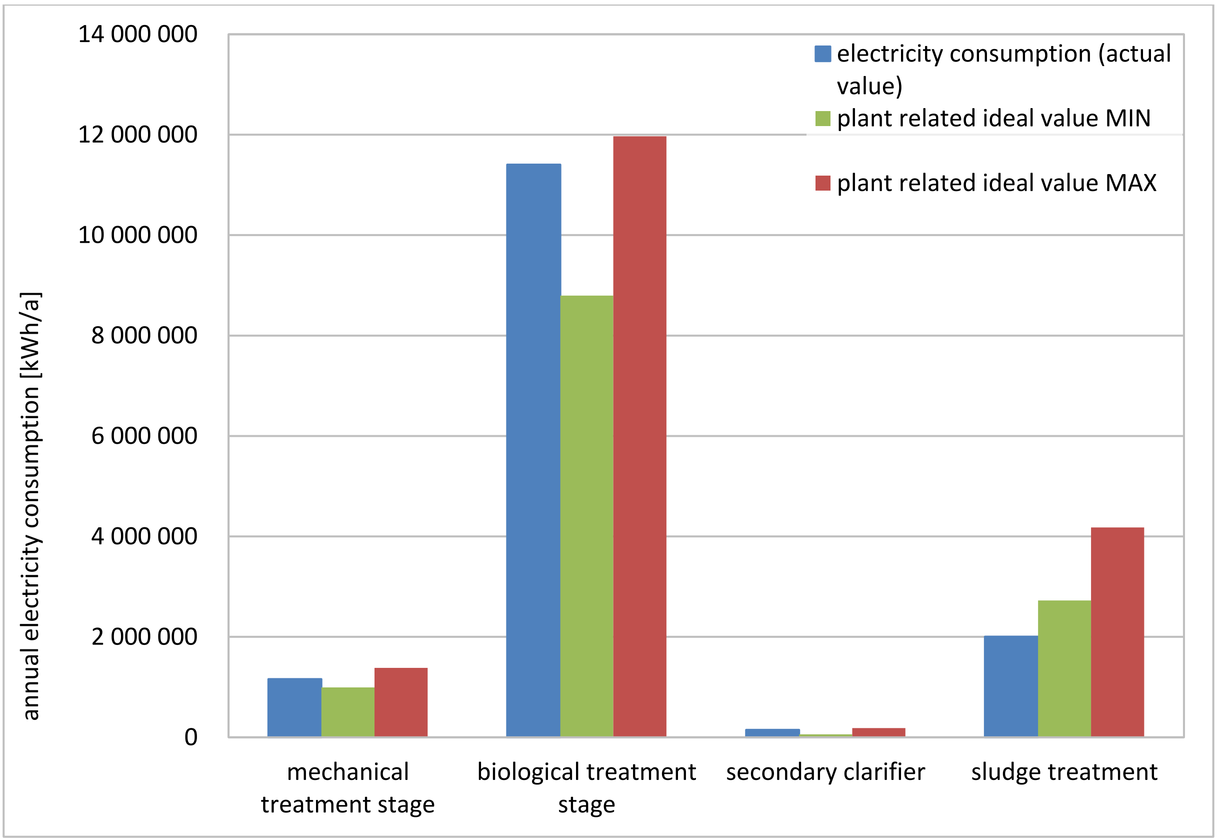

2 500 000
2 000 000
1 500 000
1 000 000
500 000
0
annual electricity consumption [kWh/a]
2 200 733
1 211 568
1 616 415
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX

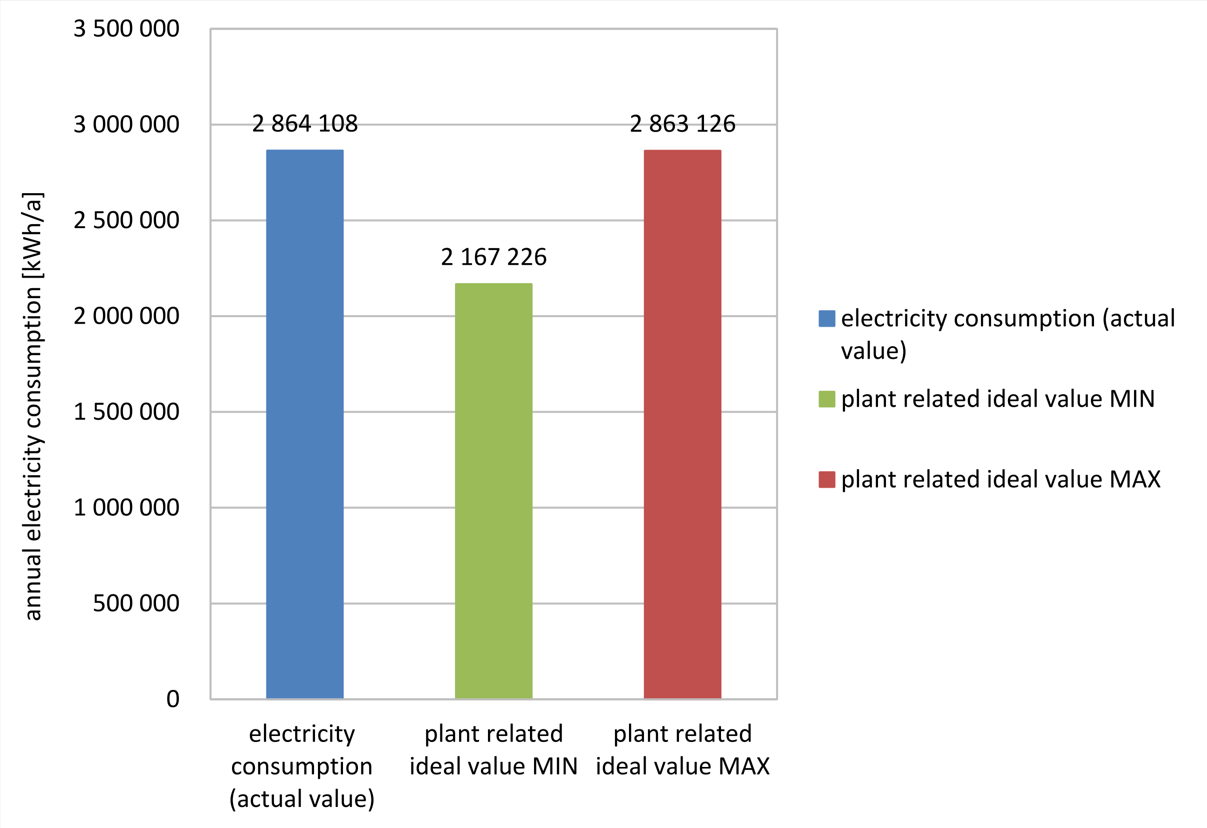

1 400 000
1 200 000
1 000 000
800 000
600 000
400 000
200 000
0
annual electricity consumption [kWh/a]
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX
mechanical treatment stage
biological treatment stage
secondary clarifier
sludge treatment

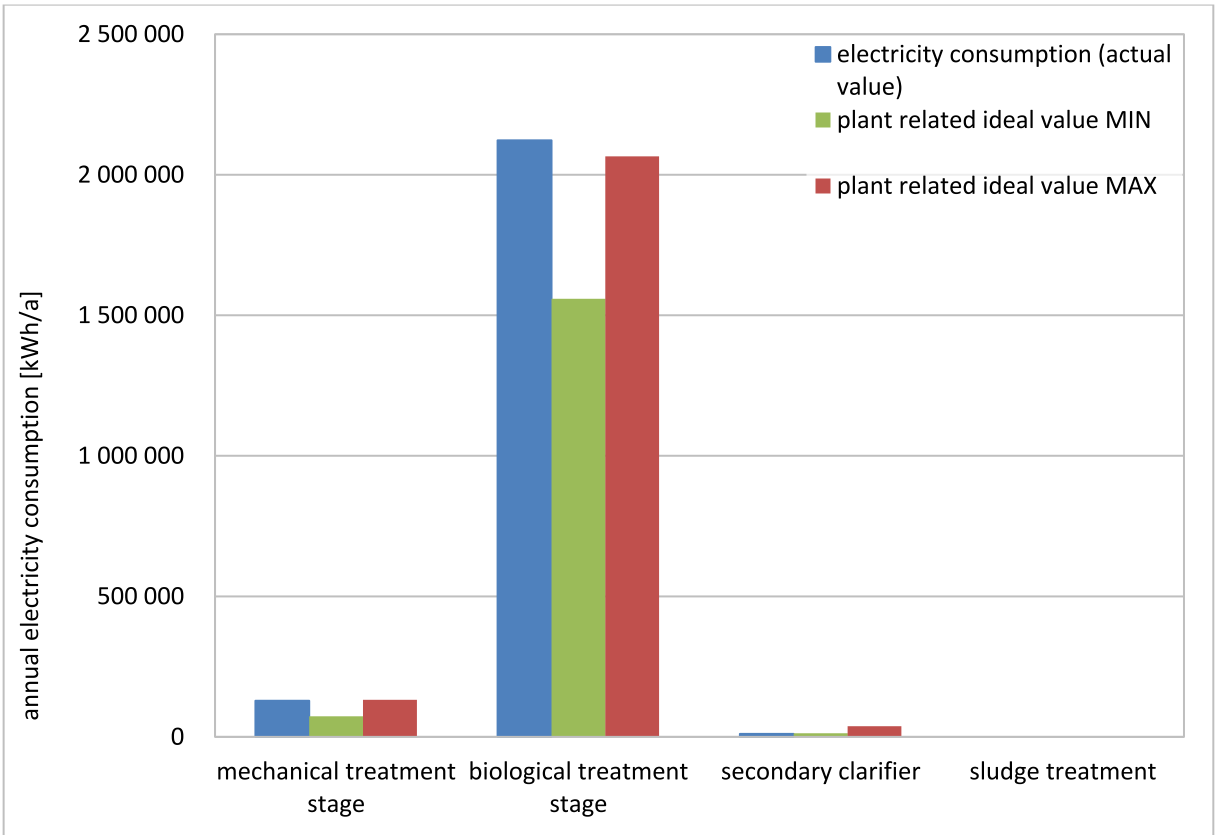

1 400 000
1 200 000
1 000 000
800 000
600 000
400 000
200 000
0
annual electricity consumption [kWh/a]
1 286 900
766 253
1 054 237
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX


600 000
500 000
400 000
300 000
200 000
100 000
0
annual electricity consumption [kWh/a]
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX
mechanical treatment stage
biological treatment stage
secondary clarifier
sludge treatment


30 000 000
25 000 000
20 000 000
15 000 000
10 000 000
5 000 000
0
annual electricity consumption [kWh/a]
21 423 023
20 323 395
26 452 356
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX


14 000 000
12 000 000
10 000 000
8 000 000
6 000 000
4 000 000
2 000 000
0
annual electricity consumption [kWh/a]
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX
mechanical treatment stage
biological treatment stage
secondary clarifier
sludge treatment


annual electricity consumption [kWh/a]
3 500 000
3 000 000
2 500 000
2 000 000
1 500 000
1 000 000
500 000
0
2 864 108
2 167 226
2 863 126
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX


annual electricity consumption [kWh/a]
2 500 000
2 000 000
1 500 000
1 000 000
500 000
0
electricity consumption (actual value)
plant related ideal value MIN
plant related ideal value MAX
mechanical treatment stage
biological treatment stage
secondary clarifier
sludge treatment

WWW.IWAMA.EU

IWAMA project aims at improving wastewater management in the Baltic Sea Region by developing the capacity of the wastewater treatment operators and implementing pilot investments to increase the energy efficiency and advance the sludge handling.

The project is funded by the Interreg Baltic Sea Region Programme 2014–2020.

Budget: EUR 4.6 million

Duration: March 2016–April 2019

SMART ENERGY MANAGEMENT AUDIT CONCEPT – COMBINED AUDIT REPORT

Published: April 2019

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