



GUIDELINES FOR USING THE SMART SLUDGE MANAGEMENT AUDIT (SSMA) TOOL

Developed in the framework
of the project IWAMA – Interactive Water Management

GUIDELINES FOR USING THE SMART SLUDGE MANAGEMENT AUDIT (SSMA) TOOL

Detailed information and explanations for filling out and understanding the SSMA tool

This document gives more detailed information and explanations about important aspects of filling Smart sludge management audit tool. Guidelines are given about the structure of the audit tool, technical tips for filling the tool, explanations for content of automatic calculations and definitions for used terms.

Previously there was no sludge management self-audit concept available for municipal WWTPs, as sludge management practicalities and technologies vary largely in the Baltic Sea Region (BSR) based on location and size of the WWTPs. This tool was developed to give operators opportunity to perform a sludge self-audit on a WWTP. Please note that, although this audit can be used by municipal WWTPs of all sizes, it is not meant for plants treating a high share of industrial wastewater. In this case, results might be misleading. The aim of the sludge management auditing is to evaluate sludge treatment, compare achieved parameters with other WWTPs in the Baltic Sea Region, find (potential) gaps and give recommendations for development. Although sludge management is one of the most expensive processes in WWT, smart operation could substantially increase the cost-efficiency.

The SSMA tool and this guidelines document have been developed in the Interreg BSR funded IWAMA project and should be distributed for free. We issue no guarantee on the correctness and completeness of the information and results in this tool. Liability claims referring to material or immaterial damages, which are caused by use or non-use of the presented information or the application of incorrect or incomplete information, are categorical excluded. In case of interesting information or discoveries made using the SSMA concept or tool, we recommend consulting an outside expert before making any decisions with potentially financial implication.

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1. GENERAL INFORMATION

This document gives more detailed information and explanations about important aspects of filling Smart sludge management audit tool. Guidelines are given about the structure of the audit tool, technical tips for filling the tool, explanations for content of automatic calculations and definitions for used terms.

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Audit tool contains 8 sheets:

1. Disclaimer
2. General information and short introduction how to use the tool
3. Symbols and abbreviations used in the tool
4. Data input table
5. Data sheet for water and sludge analysis
6. Figures and results – regional comparison
7. Audit results and summary

Only sheets “Data input table” and “Data sheet for water and wastewater analysis” are necessary to fill in. Submitted data is the base for all summarising graphs and results, which give the result of the audit. Duration of performing sludge audit in WWTP depends on the size of the plant and availability of data.

Please start with sheet “Data input table” and fill rows 10-21 after which sheet “Data sheet for water and sludge analysis” should be filled in before following rows.

Specific information, explanations for calculations and error checks and background information are given for the sheets “Data input table”, “Data sheet for water and sludge analysis”, “Figures and results – regional comparison” and “Audit results and summary”. First three sheets in the SSMA tool should be self-explanatory and therefore are not included in this guidelines document.

NB! By Microsoft Excels own problems dealing with macros, the “Undo” and “Redo” buttons don’t always work when changing something in the SSMA tool. That means deleting or editing some values can’t be often be automatically rewound, the same also applies to pressing any buttons or doing any selections. Please try to use the tool with this in mind as it might be a minor complication to people used to working with MS Excel.

2. SMART SLUDGE MANAGEMENT AUDIT GUIDELINES

2.1 Section 1 - Data input table on sheet “Input”

General rules

Data input table is on the 4th Excel sheet named “Input”. The table consists of 5 columns: “Characteristic”, “Value”, “Unit”, “Error check” and “Description and additional information” (see Fig. 1). It is necessary to fill only the column “Value”.

- Please note that given values have same unit as it is given in row “Unit” to avoid misleading results of audit.
- Different rows will be opened based on answers chosen from drop-down menus; therefore, it is reasonable to fill the table successively.
- Previously given data (values and units) should be checked when automatically calculated values seem to be incorrect. Rows connected with calculated values are described in this manual.

Data input table				
General information				
Plant name:				Process data and create audit results
Reporting year:				
Choose language:	English			
1) Wastewater treatment				
Characteristic	Value	Unit	Error check	Description and additional information
WWTP actual capacity (PE)		[PE]		Please insert real capacity not dimensioned capacity
WWTP capacity by COD (PE _{COD,120})		[PE]		Is calculated based on influent COD concentration (data asked on next sheet) and Q (1 PE = 120 g COD/d). Coloured yellow if difference between calculated and reported PE values more than 15% and red if more than 30%.
Average daily flow rate (Q)		[m ³ /d]		Average daily flow rate for the year, flow rate based on reported PE is compared to other WWTPs in the BSR, marked yellow if out of average 50% (81-156 L/PE per day) and red if out of average 80% (60-245 L/PE per day) of collected answers.

Figure 1 - Columns on the data input table

Three different colours in column “Value” mean the method of data submission (Fig 2). Orange colour requires submitting the value. Correct value should be chosen from a drop-down list when the cell is coloured green and it is not possible to write any other answer. Different sections will be opened based on chosen values from drop-down lists. Please note that the order of given answers is same in drop-down list as it is given in column “description and additional information”; it is important when another language is used for filling the tool because drop-down lists are not translated and correct answer could be chosen from column “G”. It is not possible to change values from cells coloured blue, because these are calculated values (calculations are made automatically based on previously given data).

Common legend:
Write values
Choose values from drop-down list
Calculated/closed values

Figure 2 - Common legend for the data input table

Accuracy of submitted information is essential in order to obtain reliable results from the audit. Estimated values could be submitted if exact values are unknown (e.g. total solids content of raw or thickened sludge), however, error control should be followed to prevent bigger mistakes.

Error check cells (column E) are for avoiding bigger errors with data. In case come cell turns to yellow or red, we recommend checking the data connected to that (specific cells connected to each error check will be mentioned in this manual). If you are sure the values are correct, you can proceed, even though the cells are yellow/red. If the error check cell has a border but no colour, some data might be missing preventing the error checking. In that case please refer to the specific error check cell in this guidelines document to see which values the error check is based on and make sure those are provided correctly.

Subsection 1 - Wastewater treatment

This subsection asks for the main information of WWTP and biological treatment, used as a basis of calculation for primary and secondary sludge amounts, sludge age, hydraulic retention time (HRT) etc. It's worth repeating that it is recommended to **with this section and fill in rows 10-24 after which sheet "Data sheet for water and sludge analysis" ("Laboratory data") should be filled in before continuing with next rows in this data section.** This is the only recommended "jump" in filling in the tool, everything else should be filled in in order, starting from the top of the page and moving downwards.

One of the most important cells in this section is the toggle for primary clarification (Cell "K21"). Selecting "Yes" or "No" for the primary clarification opens up large sections in both "Data input table" and "Data sheet for water and sludge analysis". Many other calculations throughout the tool also check this toggle, therefore please be sure to not leave it empty!

Following background calculations are used in this subsection:

- **Cell "K17" - WWTP capacity by COD ($PE_{COD,120}$).** In order to evaluate all WWTPs on the same scale, COD based population equivalents are calculated and subsequently used in all other calculations where PE is used as a base. Calculation done based on COD concentration in influent and average daily flow rate (Q). $1\text{ PE} = 120\text{g COD d}^{-1}$.
- **Cell "K31" – total volume of biological tanks (V_{Bio}).** As written in the tool, this is calculated based on the sum of basins reported in the cells before. If the calculated total volume is incorrect, please try to adjust separate tank volumes to achieve the correct answer. The separate tank volumes are not used by the tool for further calculations so only the total volume needs to be precise.
- **Cell "K32" - HRT of biological treatment.** Calculation of HRT is based on flow rate reported in "K18" and total volume of biological tanks calculated in "K31", if problems the calculation (V_{Bio}/Q) is incorrect, please check those values.

- Cell “K35” – calculated simple t_{ss} in the biological treatment. Calculation of t_{ss} was done according to German standard ATV-DVWK-A 131E (ATV-DVWK Standard 2000):

$$t_{ss} = \frac{V_{AT} * SS_{AT}}{Q_d * B_{d,BOD}}$$

Equation 1 – simple sludge age calculation, with t_{ss} being simple sludge age, V_{AT} volume of biological reactor (previously calculated V_{Bio} was used), SS_{AT} MLSS in biological reactor, Q_d daily flow rate and $B_{d,BOD}$ daily BOD₅ load to biological reactor. If primary clarification was not used or laboratory data of BOD₅ after clarification was not provided, the $B_{d,BOD}$ was used as influent BOD₅ load.

Following error checks are used in this subsection:

- Cell “M17” – difference between reported PE and calculated $PE_{COD,120}$. Shows the accuracy between the $PE_{COD,120}$ calculated value used in this tool and the PE value reported (used) by the WWTP itself. Following markings are possible:
 - “green” if the difference is less than 15%,
 - “yellow” if between 15% and 30%,
 - “red” if over 30%.

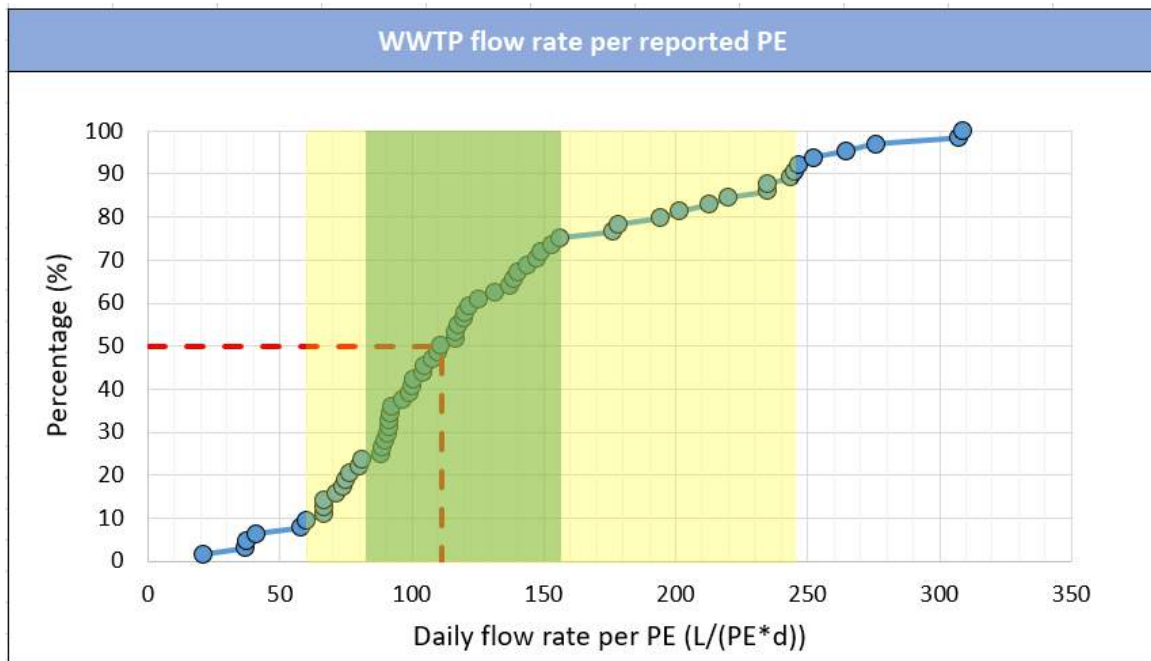


Figure 3 - The cumulative frequency graph of WWTP daily flow rate per reported PE, based on data collected from 64 WWTPs in the Baltic Sea region. The striped red line shows the median value. The green highlight shows the results between 25th and 50th percentile, yellow highlight results between 10th and 90th percentiles.

- Cell “M18” – difference between reported flow rate and reported PE. Compares the flow rate by PE per day with the benchmark values based on key figure collection in the BSR region. Following markings are possible (Figure 3):
 - “green” if the calculated value is between the 25th and 75th percentile of collected answers (81-156 L PE⁻¹ d⁻¹),
 - “yellow” if the value is between 10th and 90th percentile (60-245 L PE⁻¹ d⁻¹),

- “red” if outside of aforementioned boundaries.
- Cell “M32” – difference between calculated HRT and commonly accepted optimal HRT range. Shows possible errors in HRT calculation or indicates WWTP configurations which differ greatly from common municipal plants. If the calculation is correct and still marked “yellow”, calculated secondary sludge amounts and other biological treatment parameters might be outliers compared to other municipal WWTPs. Following markings are possible:
 - “green” if value is between 0.45 – 2 days,
 - “yellow” if outside of aforementioned boundaries.
- Cell “M34” – difference between reported and calculated sludge age. If reported and calculated sludge ages differ greatly, the sludge age calculation should be checked. It is important to understand, that only simple sludge age is calculated, without taking into account extra sludge created from chemical phosphorus precipitation. If the calculation is correct but still different from the reported sludge age, this error check can be disregarded as the values used for comparison with other WWTPs are also calculated simple sludge ages. Therefore, the results of the comparison should still apply. Following markings are possible:
 - “green” if values differ less than 20%,
 - “yellow” if values differ more than 20%.
- Cell “M35” – difference between common sludge age range and calculated sludge age. Can identify if there is bigger issue with the calculation of sludge age, resulting in sludge ages different than the normal range. Can also show error if the sludge age in reactor is very high, in that case disregard the error. Following markings are possible:
 - “green” if calculated sludge age is between 10-50 days,
 - “yellow” if calculated sludge age is out of the 10-50 day range.

Subsection 2 – External sludge and other substrates

The external sludge and other substrates subsection is fairly straightforward, no calculations or error checks are used and only basic data needs to be reported.

If industrial wastewater is accepted, but the proportions are not known, the cells “K41” and “K42” can be left empty. These values are not used in calculation, while if some results need to be evaluated manually (outside consultation) these values provide important background information.

If external sludge is accepted into one of the processes in the WWTP and cell “K44” is marked “Yes”, specifying questions open. Please fill them out as well, as specifying which process the sludge goes to opens up further questions in the specific process section and influences the calculated sludge amounts in the specific treatment process. If the external sludge path is not specified, the calculated sludge volumes in specific treatment steps might be incorrect and show errors. “Other” in this section mostly refers to external sludge added into more advanced sludge treatment process (for example sludge added to drying or to incineration).

If external sludge is added to multiple processes then please report the amount of external sludge added to digestion as biodegradables (subsection 4, cells “K94” and “K95”, if biodegradables are also accepted into digestion please add the biodegradable and external sludge amounts) and report the other flow of external sludge in this section (“Thickening”, “Dewatering” or “Other”). If the additions to a specific process are less than 1% from the total mass, these flows can be disregarded if necessary.

Subsection 3 – Thickening

The thickening subsection consists of three similar parts, for primary, secondary and combined thickening. The questions for each of the thickening steps are mostly the same, with major differences only in expected values and calculations. In all three thickening subsections, chemical (polymer) dosing is presented as a separate question, answering “Yes” to the specific question opens another question about the amount. If no chemical is dosed to the specific process, please answer “no” to the chemical dosing question, which should automatically close the following question about the dosed amounts.

The primary and combined thickening open only if primary clarification is selected in cell “K21”, combined thickening has an extra cell “K62”, which toggles either separate or combined thickening questions. It is important, that the volumes, solids contents and masses of sludge asked in this section are all meant after the specific process, so reporting values taken before the process is incorrect and may negatively influence overall results.

Many error checks use “commonly accepted optimal values” in comparison to the reported sludge production amounts. These “commonly accepted optimal values” are from a textbook in the Biological Wastewater treatment series published by IWA Publishing (*Andreoli, Cleveson Vitorio, Marcos von Sperling, and Fernando Fernandes. 2007. “Sludge Treatment and Disposal.”*).

If dewatering is used directly after biological treatment, the thickening subsection can be left empty. At the same time the SSMA tool doesn’t achieve many results for very small WWTPs, therefore some cells, error checks and figures might be missing in such cases.

Following background calculations are used in this subsection:

- **Cell “K59” – total mass of primary sludge after thickening.** If both sludge volume (“K57”) and solids content (“K58”) are given, this will be calculated automatically. If the calculated value is wrong, please check the volume or solids content cells. If volume or solids content is unknown, while the total mass is measured, please leave the volume and solids content empty to bypass the automatic calculation and report the sludge mass in cell “K59”.
- **Cell “K60” – calculated mass of primary sludge.** Based on industry standards, the primary sludge amount should be equal to the load of suspended solids removed with primary clarification. This calculation is based on cell “K18” (Average daily flow rate) in the “Input” section and cells “K11” and “K12” provided in “Laboratory data” section. If one of these values is missing, this cell should be empty. On the other hand, if external sludge is accepted and added to primary thickening, the reported value from cell “K46” is added to the result. The equation used for the calculation of primary sludge mass is the following:

$$SP_{d,PC} = (SS_d - SS_{PC}) \times Q_d + SP_{d,EX,PC}$$

Equation 2 – daily primary sludge production calculation, with $SP_{d,PC}$ being daily primary sludge production (kg TS d⁻¹), SS_d suspended solids concentration in the influent, SS_{PC} suspended solids concentration after primary clarification, Q_d average daily flow rate and $SP_{d,EX,PC}$ external sludge added into primary thickening.

- **Cell “K69” – total mass of mixed sludge after thickening.** If both sludge volume (“K67”) and solids content (“K68”) are given, this will be calculated automatically. If the calculated value is wrong, please check the volume or solids content cells. If volume or solids content is unknown, while the total mass is measured, please leave the volume and solids content empty to bypass the automatic calculation and report the sludge mass in cell “K69”.
- **Cell “K70” – calculated mass of mixed sludge.** Based on the industry standards, the mixed sludge amount should be equal to the sum of primary and secondary sludge, therefore equations 2 and 4 are used to calculate it. If external sludge is accepted and added to mixed thickening, the reported value from cell “K46” is added to the result. As the mass on mixed sludge depends on many parameters, which are already

outlined in specific parameter calculations, the explanations for cells “K60” and “K79” should be read if “K70” is blank or shows an incorrect result. The equation used for the calculation of mixed sludge mass is the following:

$$SP_{d,MIX} = SP_{d,PC} + SP_{d,WAS} + SP_{d,EX,MIX}$$

Equation 3 – daily mixed sludge production calculation, with $SP_{d,MIX}$ being daily mixed sludge production (kg TS d⁻¹), $SP_{d,PC}$ daily primary sludge production, $SP_{d,WAS}$ daily secondary (waste activated sludge) production and $SP_{d,EX,MIX}$ external sludge added into the mixed sludge thickening.

- **Cell “K78” – total mass of secondary sludge after thickening.** If both sludge volume (“K76”) and solids content (“K77”) are given, this will be calculated automatically. If the calculated value is wrong, please check the volume or solids content cells. If volume or solids content is unknown, while the total mass is measured, please leave the volume and solids content empty to bypass the automatic calculation and report the sludge mass in cell “K78”.
- **Cell “K79” – calculated mass of secondary sludge.** Calculation is done according to German standard ATV-DVWK-A 131E (ATV-DVWK Standard 2000), while it is important to note that **extra sludge production from phosphorus precipitation is not considered in this calculation**. This calculation is based on many previously reported parameters such as cells “K18” (average daily flow rate), “K19” (average temperature in aeration tank) and “K35” (calculated sludge age) in the “Input” section and cells “E11” or “E12” and “K11” or “K12” (depending on whether primary clarification is used and the corresponding data is provided) in “Laboratory data” section. The equations used for the calculation of secondary sludge mass are the following:

$$SP_{d,C} = B_{d,BOD} \times \left(0.75 + 0.6 \times \frac{X_{SS,IAT}}{C_{BOD,IAT}} - \frac{(1 - 0.2) \times 0.17 \times 0.75 t_{SS} \times 1.072^{(T-15)}}{1 + 0.17 \times t_{SS} \times 1.072^{(T-15)}} \right)$$

Equation 4 – daily secondary sludge production from carbon removal calculation, with $SP_{d,C}$ being daily secondary sludge production from carbon removal (kg TS d⁻¹), $B_{d,BOD}$ daily BOD₅ load, $X_{SS,IAT}$ concentration of the suspended solids in the influent to the biological reactor, $C_{BOD,IAT}$ concentration of BOD₅ in the homogenised sample in the influent to the biological reactor, t_{SS} sludge age in reference to the volume of biological reactor and T the average temperature in the biological reactor.

$$SP_{d,WAS} = SP_{d,C} + SP_{d,EX,WAS}$$

Equation 5 – daily total secondary sludge production calculation, with $SP_{d,WAS}$ being daily total secondary sludge production, $SP_{d,C}$ daily secondary sludge production from carbon removal and $SP_{d,EX,WAS}$ daily external sludge added to secondary sludge thickening.

Following error checks are used this subsection:

- **Cell “M59” – difference between reported primary sludge production and commonly accepted optimal primary sludge production.** Compares reported primary sludge production to optimal primary sludge production of 35-45 g TS PE⁻¹ d⁻¹. Some leniency (20%) is given as WWTPs can’t always achieve the optimal values, therefore the range of 28-54 g TS PE⁻¹ d⁻¹ is used in the comparison. $PE_{COD,120}$ value from “K17” is used in the calculation as the WWTPs size. **As primary sludge is rich in organic carbon, this error check indicates if the WWTP is maximising the biogas potential from primary clarification. If the audited WWTP uses anaerobic digestion and this specific error check is turned “yellow”, attention should be given to the reasons** as low primary sludge production is a common parameter resulting to low biogas production. If the error check is “yellow” because the influent SS concentration is very high and more primary sludge is produced, please disregard this result (upper limit of 54 g TS PE⁻¹ d⁻¹ is mostly used to show possible errors in reported data). If the influent SS concentration is very low or WWTP has knowingly reduced primary clarification to carry more organics to the biological treatment stage, this error check can be mainly disregarded. Following markings are possible:
 - “green” if reported primary sludge production is between 28-54 g TS PE⁻¹ d⁻¹,
 - “yellow” if reported primary sludge production is outside of aforementioned boundaries.
- **Cell “M60” – difference between reported and calculated primary sludge production.** This error check shows if the primary sludge production based on SS loss (and possible external sludge addition) is similar to

reported primary sludge production. If the error check is marked “yellow”, both values should be checked (specific calculations and input parameters are explained in the previous “background calculations” subsection in the current guidelines document) as no major difference can be explained between the two values (SS concentrations, sludge mass and daily flow rate should all be reported as yearly averages). Following markings are possible:

- “green” if values differ less than 20%,
 - “yellow” if values differ more than 20%.
- Cell “M69” – difference between reported mixed sludge production and commonly accepted optimal values. Compares reported mixed sludge production to optimal mixed sludge production of 60-80 g TS PE⁻¹ d⁻¹. Some leniency (20%) is given as WWTPs can’t always achieve the optimal values, therefore the range of 48-96 g TS PE⁻¹ d⁻¹ is used in the comparison. PE_{COD,120} value from “K17” is used in the calculation as the WWTPs size. As with primary clarification, **this error check should also be regarded important as it is connected to biogas production during anaerobic digestion**. If mixed sludge production is not measured separately (flow meter, etc), primary and secondary sludge production should be checked to in case of “yellow” results in this error check. Also, if the error check in cell “M59” is “yellow” (primary sludge production is lower than optimal), it could also influence the result here. Following markings are possible:
 - “green” if reported mixed sludge production is between 48-96 g TS PE⁻¹ d⁻¹,
 - “yellow” if reported mixed sludge production is outside of aforementioned boundaries.
- Cell “M70” – difference between reported and calculated mixed sludge production. This error check shows if the calculated sum of primary and secondary sludge production and possible external sludge addition (equation 3) is similar to the reported mixed sludge amounts. If the error check in cell “M60” is yellow, it also influences the result here, while if the “M60” error check is “green” and this one is “yellow”, problems should be searched from the secondary sludge calculations (outlined in equation 4). As many different parameters influence this result, variance is possible with this error check due to minor inconsistencies in data – therefore if base data is checked and no major problems are found, the “yellow” marking in this error check can be disregarded. Following markings are possible:
 - “green” if values differ less than 20%,
 - “yellow” if values differ more than 20%.
- Cell “M78” – difference between reported secondary sludge production and commonly accepted optimal values. Compares reported secondary sludge production to optimal secondary sludge production of 25-35 g TS PE⁻¹ d⁻¹. Some leniency (20%) is given as WWTPs can’t always achieve the optimal values, therefore the range of 20-42 g TS PE⁻¹ d⁻¹ is used in the comparison. PE_{COD,120} value from “K17” is used in the calculation as the WWTPs size. While secondary sludge production and therefore **this error check is important to WWTPs with anaerobic digestion**, it should be noted that with very low influent BOD₅ or SS concentrations (especially with combined stormwater sewer systems) or with high sludge age, the secondary sludge production could be lower than the recommended amount. For a WWTPs without anaerobic digestion this error check is not as important and can be mostly disregarded, while we still recommend double-checking the reported data. Following markings are possible:
 - “green” if reported secondary sludge production is between 20-42 g TS PE⁻¹ d⁻¹,
 - “yellow” if reported secondary sludge production is outside of aforementioned boundaries.
- Cell “M79” – difference between reported and calculated secondary sludge production. This error check shows if the calculated secondary sludge production (together with the possible addition of external sludge) is similar to reported secondary sludge production. If the error check is “yellow”, both the reported and calculated values should be checked, the specific cells affecting the calculation are explained in the previous “background calculations” subsection” and can be seen from equation 4. These values can differ however, as sludge production from phosphorus removal is not taken into account in the secondary sludge production, therefore the calculated amount can be significantly smaller, especially if influent phosphorus

concentrations are higher than average and phosphorus is mainly chemically precipitated (1 kg P d^{-1} removed with bioP amounts to around 3 kg TS d^{-1} , while chemical precipitation results in more sludge (around 6.8 kg TS d^{-1} with Fe^{3+} and 5.3 kg TS d^{-1} with Al^{3+}). Following markings are possible:

- “green” if values differ less than 20%,
- “yellow” if values differ more than 20%.

Subsection 4 – Digestion

The digestion subsection is opened by the toggle at cell “K84”, therefore if the cell is marked with “No” or is empty, the digestion subsection is closed. The digestions subsection also includes questions about external sludge and biodegradables addition, therefore some cells in this subsection will only open with specific choices made in the SSMA, most important of which being:

- Cell “K87” – toggling of either parallel or sequential mode for digesters. Is only asked if the WWTPs reports 2 or more digesters in the cell “K86”. Parallel mode refers to digestion where both digesters are fed and operate separately, while sequential mode refers to digestion, where the feed goes through multiple steps of digestion in different digesters (with disintegration, etc in between two steps). If both modes are used in the WWTP, please select “Sequential”.
- Cell “K89” – temperature of treatment (2nd digestion). Is only asked if “Sequential” mode is toggled in cell “K87”. This value is not used in calculation, while if some results need to be evaluated manually (outside consultation) the value might provide important background information.
- Cell “K93” – average amount of sludge from external WWTPs added to digestion per day. Is only asked if previously in subsection 2 (External sludge and other substrates) the cell “K44” is marked as “yes” (accepting external sludge) and cell “K45” (the path of external sludge) is marked as “Digestion”. If the cell “K93” is open, please provide a value as it will be used in calculating the total mass loaded into the digester. If specific value is unknown and presents a very small fraction ($<1\%$) of total mass, we recommend disregarding this amount completely and removing this information from subsection 2 cells “K44” and “K45”. If the specific value is unknown but the fraction from total mass is larger than 1%, please try to use estimation based on the data you have. **It is worth mentioning daily total solids load of external sludge is asked in this cell**, therefore if only volume or wet mass is known, please also try to estimate the MLSS in the external sludge.
- Cell “K95” – average amount of biodegradables added to digesters per day. Is only asked if accepting biodegradable waste to the digester is marked “yes” in cell “K94”. **It is worth mentioning daily total solids load of biodegradables is asked in this cell**, as other amounts reported and calculated are also in the same units (kg TS d^{-1}). Therefore, if only volume, wet mass or COD load is known, please try to estimate the total solids load.
 - **NB! If by instruction received in subsection 2** (in case of multiple paths for external sludge) **you are reporting external sludge in this cell**, please make sure that “Yes” is selected in cell “K94” to open up the cell “K95” even if biodegradables are not actually added. If both biodegradables and external sludge are added to the digestion, please add up the amounts and report the sum.

Following background calculations are used in this subsection:

- **Cell “K91” – total volume of digesters.** This value is calculated based on the number of digesters reported in cell “K86” and the volume of one digester reported in cell “K90”. As stated in the SSMA tool, if multiple digesters are used and have different volumes, average volume would need to be calculated and reported. In terms of priority, please make sure the calculated value in cell “K91” is correct, as the total volume is used in multiple calculations as a base value. Also, this value should indicate the actual usable volume in digesters

at the current time, therefore older plants should not include unused digesters waiting for repairs in this total volume.

- **Cell “K96” – calculated amount of mass before digestion.** Sums up different streams of sludge and biodegradables reported previously in the tool. Depending on what has been selected and reported, the calculation uses total mass of primary sludge after thickening from cell “K59”, total mass of secondary sludge after thickening from cell “K78” or total mass of mixed sludge after thickening from cell “K69”, average amount of external sludge added to digestion daily from cell “K93” and average amount of biodegradables added to digesters per day from “K95”. This calculation serves as a quick check of different amounts reported so far, to give the WWTPs an option to see whether the sum of streams reported so far is similar to the actual daily load into the digester. This result is not used in the calculations further, only in the error check in cell “M101” as comparison to the reported daily digester inflow. If the result of this calculation is incorrect, please check if every value used in this calculation is reported as kg TS d^{-1} , as this is the most common mistake, especially reporting external sludge and biodegradables.
- **Cell “K101” – average daily amount of inflow to the digester.** If both concentration of sludge at the influent of the digester (“K99”) and daily flow (“K100”) are given, this will be calculated automatically. If the calculated value is incorrect, please check if data in those two cells. If the concentration of influent or daily flow is unknown, while the daily inflow of mass is measured, please leave the previous two cells empty to bypass the automatic calculation and report the daily inflow data directly in cell “K101”.
- **Cell “K105” – total amount of sludge after digestion.** If both sludge volume (“K103”) and solids content (“K104”) are given, this will be calculated automatically. If the calculated value is wrong, please check the volume or solids content cells. If volume or solids content is unknown, while the total mass is measured, please leave the volume and solids content empty to bypass the automatic calculation and report the sludge mass in cell “K105”.

Following error checks are used this subsection:

- **Cell “M91” – comparison of reported total volume of digesters and regional data of digester volume by WWTP size.** Compares digester size per 1000 PE to the benchmark values based on key figure collection in the BSR region. $\text{PE}_{\text{COD},120}$ value from “K17” is used in the calculation as the WWTPs size, the comparison value is acquired by dividing the total volume of digesters with $\text{PE}_{\text{COD},120}$ value and multiplying in by 1000 to get the unit of m^3 per 1000 PE. This check can be useful to **compare the capacity of the digestion in the WWTP with other WWTPs in the region.** “Yellow” marking might indicate the WWTP has lower digestion capacity (and therefore lower potential for biogas production and possible future energy neutrality) than other WWTPs in the region. Digester volume per 1000 PE also indicates how much extra substrates (both external sludge and biodegradables) the WWTPs can accept compared to the size of biological treatment. If the digesters are fully loaded and the error check is marked “yellow” or “red”, it might be feasible to consider investments to new digesters to increase the long-term energy production potential of the WWTP. Nevertheless, in the previous case, please conduct a separate feasibility study or consult an expert before making any decisions with possible financial implications. Following markings are possible (Figure 4):
 - “green” if the value is between the 25th and 75th percentile of collected answers ($28\text{--}55 \text{ m}^3 \text{ 1000 PE}^{-1}$),
 - “yellow” if the value is between 10th and 90th percentile ($22\text{--}66 \text{ m}^3 \text{ 1000 PE}^{-1}$),
 - “red” if outside of aforementioned boundaries.

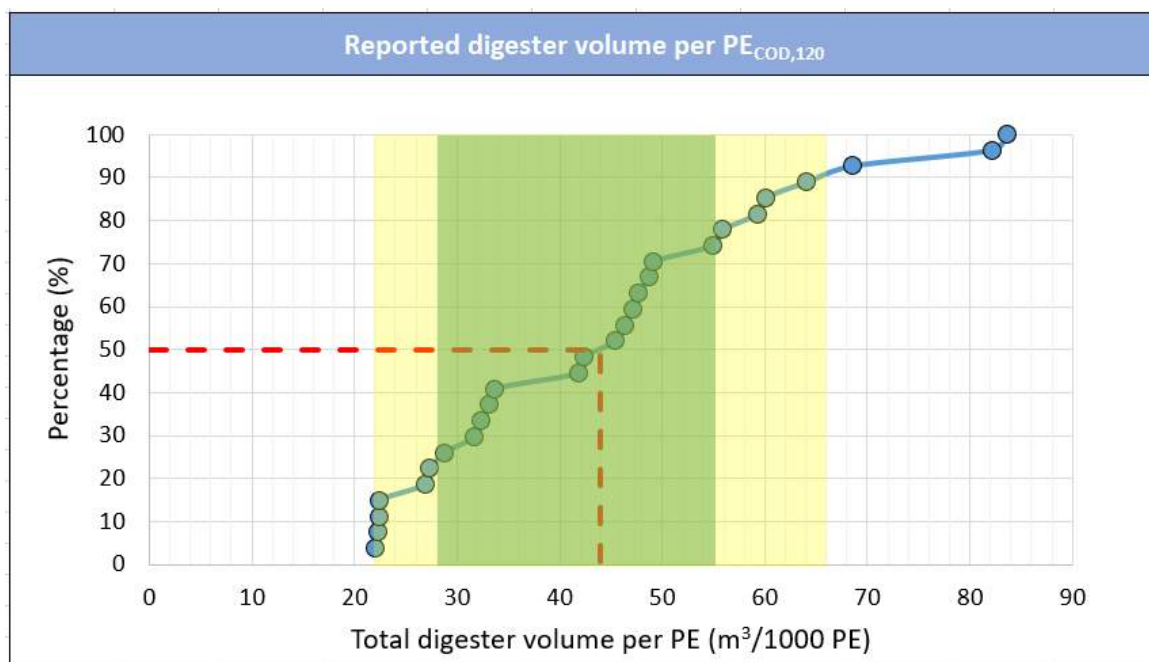


Figure 4 – The cumulative frequency graph of reported digester volume per 1000 PE, based on data collected from 27 WWTPs in the Baltic Sea region. Calculated $PE_{COD,120}$ was used for this figure. The striped red line shows the median value. The green highlight shows the results between 25th and 50th percentile, yellow highlight results between 10th and 90th percentiles.

- Cell “M96” – error check of reported streams going into the digester. A quick check showing if any of the reported streams (primary, secondary or mixed sludge, sludge accepted from external WWTPs and biodegradables) are chosen in the tool but are missing data. If the error check is marked “yellow”, please check all the cells outlined in the guidelines document previously under cell “K96” explanations. If everything is filled correctly, this error check should always show the colour “green”. Following markings are possible:
 - “green” if all selected streams are filled with data,
 - “yellow” if any of the selected streams are missing data (corresponding cells are empty).
- Cell “M97” – comparison of reported HRT and calculated HRT based on reported digester total volume and daily flow to the digester. Indicates if different values reported are matching to show any possible errors due to incorrect units or mistakes in reporting. The reported HRT is compared to HRT calculated by dividing the total digester volume (“K91”) with daily flow to the digester (“K100”). If this error check is marked “yellow”, please check all three corresponding cells. If the digesters are not loaded fully or one digester is kept in reserve, resulting in differences between the two HRTs, then disregard this error check. Following markings are possible:
 - “green” if values differ less than 20%,
 - “yellow” if values differ more than 20%.
- Cell “M101” – comparison of reported average daily inflow and calculated amount of mass going into the digester. Calculated amount of mass from different thickening processes and external substrates (external sludge and biodegradables) shown in cell “K96” is used in this comparison. If the error check is marked “yellow”, please check all corresponding cells. Values used in the calculation of cell “K96” are outlined in this file at the corresponding paragraph. No major difference should be possible between the two values, if annual averages are estimated correctly. Following markings are possible:
 - “green” if values differ less than 20%,
 - “yellow” if values differ more than 20%.

- Cell “M106” – comparison of daily biogas production per loaded TS to regional data collected from other WWTPs. Compares biogas production per loaded TS (value from cell “K106” is divided by the value in cell “K101”) to the benchmark values based on key figure collection in the BSR region. **Please bear in mind, that this comparison is based on total loaded TS not the loaded organic content (ORL)**, therefore some WWTPs with higher organic load might achieve better results. Still, this comparison can be used to make sure the reported biogas production is in the correct range and there are no errors in reporting, while also giving an indication on how much biogas other WWTPs in the region can produce per solids load. **With very high biodegradable loading it is possible for this error check to show “yellow” or “red” marking**, as the WWTP might be outside the upper range limit (top 10% of benchmarked WWTPs). In such case, this error check can be disregarded. In other cases, in case of “yellow” or “red” markings, please check the values in cells “K101” and “K106”. Please make sure biogas volume is reported in standard cubic meters (at the temperature of 15° C and pressure of 1 atm, automatically given by most sensors). Following markings are possible (Figure 5):
 - “green” if the value is between the 25th and 75th percentile of collected answers (280-390 L kg⁻¹ TS),
 - “yellow” if the value is between 10th and 90th percentile (200-460 L kg⁻¹ TS),
 - “red” if outside of aforementioned boundaries.

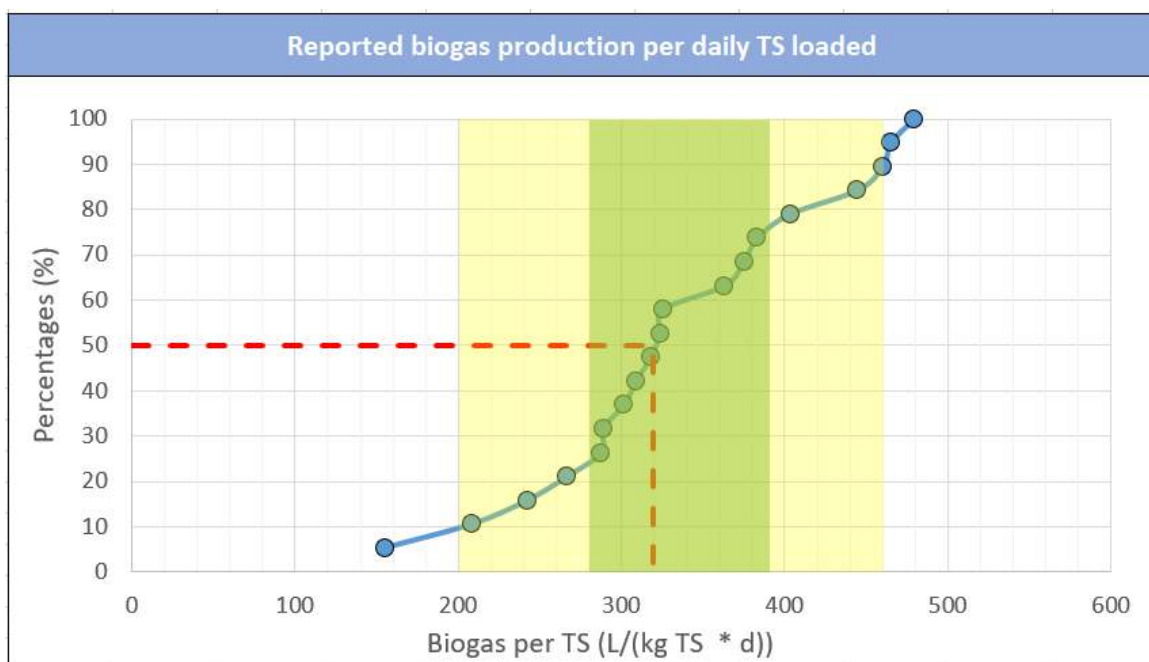


Figure 5 – The cumulative frequency graph reported biogas production per TS loaded into the digester daily, based on data collected from 19 WWTPs in the Baltic Sea region. The striped red line shows the median value. The green highlight shows the results between 25th and 50th percentile, yellow highlight results between 10th and 90th percentiles.

Subsection 5 – Dewatering

The dewatering subsection is opened by the toggle at cell “K112”, therefore if the cell is marked with “no” or is empty, the subsection is closed. The digestions subsection also includes questions about external sludge addition, polymer dosing and reject water treatment, therefore some cells in this subsection will only open with specific choices made in the SSMA, most important of which being:

- Cell “K116” – chemical consumption during dewatering. Is only asked if the toggle value in cell “K115” is set to “yes”. This value is not used in calculation, while if some results need to be evaluated manually (outside consultation) the value might provide important background information.
- Cell “K117” – average amount of sludge from external WWTPs added to dewatering daily. Is only asked if previously in subsection 2 (External sludge and other substrates) the cell “K44” is marked as “yes” (accepting external sludge) and cell “K45” (the path of external sludge) is marked as “Dewatering”. Should be closed for most of the WWTPs, this question is in most cases meant for smaller WWTPs using dewatering directly after thickening. If the cell “K117” is open, please provide a value as it will be used in calculating the total amount of sludge before dewatering. If specific value is unknown and presents a very small fraction (<1%) of total mass, we recommend disregarding this amount completely and removing this information from subsection 2 cells “K44” and “K45”. If the specific value is unknown but the fraction from total mass is larger than 1%, please try to use estimation based on the data you have. **It is worth mentioning daily total solids load of external sludge is asked in this cell**, therefore if only volume or wet mass is known, please also try to estimate the MLSS in the external sludge.
- Cell “K123” – analysis from separate reject water treatment. This question opens if separate reject water treatment is marked in previous cell (“K122”). The answer to this question opens specific places in the “Laboratory data” section (line 14 “Reject water before treatment” and line 15 “Reject water after treatment”) to report water quality parameters. These values are not used in calculation, while if some results need to be evaluated manually (outside consultation) these values might provide important background information.

Following background calculations are used in this subsection:

- **Cell “K118” – calculated amount of sludge before dewatering.** Calculates the amount of sludge that based on previous answers should come into to dewatering process. This result is not used in the calculations further besides the error check in cell “M121”. Depending on the choices made in cell “K113” following options can be used:
 - **“After biological treatment”** – calculates the daily secondary sludge production similar to equation 4 outlined previously in this file. If value is missing or incorrect, please refer to the equation and explanation of cell “K79”, where the specific cells used in the calculation are outlined. If external sludge is toggled in “K45” (the path of external sludge), adds the result from “K117” (“Average amount of sludge from external WWTPs added to dewatering daily”) to the calculation. If this value is incorrect, please check the aforementioned cells to make sure data is reported correctly. If some data is unknown and this calculation cannot be completed, this cell can be left empty, which also negates the error check in “M121”.
 - **“After thickening”** – checks if mixed sludge thickening or secondary sludge thickening was selected previously and transfers that amount (“K69” for mixed and “K78” for secondary) to cell “K118”. If primary sludge thickening is toggled and primary and secondary sludge are thickened separately, the sum of those two amounts (“K59” and “K78”) is transferred to cell “K118”. If external sludge is toggled in “K45” (the path of external sludge), adds the result from “K117” (“Average amount of sludge from external WWTPs added to dewatering daily”). If this value is incorrect, please check the aforementioned cells to make sure data is reported correctly.
 - **“After digestion”** – uses the value reported in cell “K105” (“Total amount of sludge after digestion”), if for some reason external sludge is toggled in “K45” (the path of external sludge), adds the result from “K117” (“Average amount of sludge from external WWTPs added to dewatering daily”) to the result from “K105”. If this value is incorrect, please check the aforementioned cells to make sure data is reported correctly.
- **Cell “K121” – total mass of sludge after dewatering.** If both sludge volume (“K119”) and solids content (“K120”) are given, this will be calculated automatically. If the calculated value is wrong, please check the volume or solids content cells. If volume or solids content is unknown, while the total mass is measured,

please leave the volume and solids content empty to bypass the automatic calculation and report the sludge mass in cell “K121”.

Following error check is used this subsection:

- Cell “M121” – comparison of reported total mass of sludge after dewatering and calculated amount of sludge before dewatering. Uses the calculated sludge amount from cell “K118”. Although these two values refer to different pipe-ends, no significant solids content should be lost during dewatering. If the error check is marked “yellow”, please check all corresponding cells. In the case of high solids loss during dewatering, thorough investigation into dewatering efficiency (polymer dosing, polymer effect on flocculation and dewatering speed and etc) is recommended. If due to unknown data the value in cell “K118” is missing or blank, this error check should be disregarded (no colour should be shown in the tool). Following markings are possible:
 - “green” if values differ less than 20%.
 - “yellow” if values differ more than 20%.

Subsection 6 – Biogas treatment and utilisation

The biogas treatment and utilisation subsection is only shown if anaerobic digestion is used in the WWTP (toggled by cell “K84”). In other cases, the questions in this subsection do not apply therefore this subsection is hidden from view.

The biogas subsection has 4 main toggles corresponding to different ways biogas can be used. Answering “yes” in the specific toggles opens additional questions connected to the utilisation way. Once again, please make sure all biogas volumes are reported in standard cubic meters (at the temperature of 15° C and pressure of 1 atm, automatically given by most sensors). Following utilisation ways are considered in the SSMA tool:

- **Cell “K128” – biogas sold/transferred out of the WWTP.** Refers to biogas that is not utilised by the WWTP itself but is sold or transferred to another company for energy or fuel production. This toggle also asks for specifics, whether the biogas is sold/transferred as CNG (Compressed Natural Gas, used by vehicles as fuel) or uncompressed biogas. By answering “yes” to this question (both “Yes – as CNG fuel” and “Yes – as biogas”), cell “K129” opens where the amount of biogas sold can be specified. The amount of biogas reported in this section will not be used to calculate energy and heat produced by 1 m³ of biogas in the WWTP.
- **Cell “K131” – biogas used as fuel in CHP.** Refers to biogas that is used to generate electricity and heat in a CHP (Combined Heat and Power) plant. Answering “yes” to this question opens cells “K132 – K134”, where additional questions about the amount of biogas converted and amounts of electricity and heat produced are asked. It is worth mentioning here, that **annual electricity and heat production are asked, while biogas conversion still requires daily average data**. Also heat production in a furnace or other system besides a CHP should be reported in cell “K136” and “K139”. If both CHP and direct heat generation from biogas are used, the total amount of heat produced from both can be summarised and reported in either “K134” or “K139” (please leave the other one empty to avoid double reporting in that case).
 - **NB! If heat production is not measured, please try to write some estimates. If no data can be provided, energy production figures and calculations in both the “Figures and results” and “Summary” sections will be incomplete and may provide partially incorrect results.**
- **Cell “K136” – biogas used as fuel for heat production.** Refers to biogas that is directly converted to heat in a furnace or similar equipment. Answering “yes” to this question opens cells “K137 – K139”, where additional questions about the aim of biogas conversion to heat, amount of biogas converted and amount of heat produced are asked. It is worth mentioning here, that **annual heat production is asked, while biogas**

conversion still requires daily average data. Also combined heat and electricity production in a CHP should be reported in cell “K131” and “K134”. If both CHP and direct heat generation from biogas are used, the total amount of heat produced from both can be summarised and reported in either “K134” or “K139” (please leave the other one empty to avoid double reporting in that case).

- **NB! If heat production is not measured, please try to write some estimates. If no data can be provided, energy production figures and calculations in both the “Figures and results” and “Summary” sections will be incomplete and may provide partially incorrect results.**
- **Cell “K141” – biogas burned without any energy retrieval (in flare).** Refers to biogas that is burned without any energy retrieval. Both “Yes” and “Only for emergency” options open the cell “K142” where the **annual amount** can be specified. If this value is insignificantly small, this cell can be left empty. The amount of biogas reported in this section will not be used to calculate energy and heat produced by 1 m³ of biogas in the WWTP.

Following background calculation is used in this subsection:

- **Cell “K144” – calculated total amount of biogas used daily.** Calculates the daily total biogas amount reported as sold (“K129”), used in CHP (“K132”), used in heat generation (“K138”) or burned without energy retrieval (“K142”). If this value is incorrect, please check the previously reported values.

Following error check is used this subsection:

- **Cell “M144” – comparison of total amount of biogas used daily to total amount of biogas produced daily.** Compares the value of “K144” to biogas produced in digestion “K106” to check for any errors in reporting. No major difference should be possible between two values, very minor differences can be possible due to measurements and rounding different reported amounts. If this error check is marked “yellow”, please check both reported biogas production and usage. Following markings are possible:
 - “green” if values differ less than 10%,
 - “yellow” if values differ more than 10%.

Subsection 7 – Further sludge treatment

The specific options and questions presented in this subsection depend on whether anaerobic digestion was reported previously (“K84”) or not. For WWTPs with digestion three major further sludge treatment options are presented in the SSMA (cell “K151”) – composting, drying and drying and incineration. For WWTP without anaerobic digestion also three further sludge treatment options are presented in the SSMA (cell “K150”) – humification, composting and lime stabilisation. Each of those subsections will be discussed separately in this guidelines document.

- **Humification** – by choosing “Humification” in cell “K150” additional questions will open in cells “K193” to “K198” asking for humification specifics. Please try to answer to the questions as much as possible with the information at hand, but bear in mind, these values are mostly not used in further calculations, while if some results need to be evaluated manually (outside consultation) these values might provide important background information. No specific calculations or error checks are present in this section.
 - **Cell “K196” – removal/mowing of plants (concurrent phytoremediation).** As scientific studies have shown, the plants grown on humification fields have a potential to absorb dangerous substances (heavy metals for example), which can make mowing the plants after a specific growth period worth considering. If the plants are removed in some other frequency than given as an option in this cell, please bear in mind that “At the end of the process” should be chosen if plants are removed once from one field/bed and “Annually” if plants are removed multiple times during the total duration of humification.

- **Lime stabilisation** – by choosing “Lime stabilisation” in cell “K150” additional questions will open in cells “K200” to “K202” asking for specifics. Please try to answer to the questions as much as possible with the information at hand, but bear in mind, these values are mostly not used in further calculations, while if some results need to be evaluated manually (outside consultation) these values might provide important background information. No specific calculations or error checks are present in this section.
 - Cell “K200” – type of chemical used during lime stabilisation. The choice has been given between two of the most common lime substances used in lime stabilisation – quicklime, also known as calcium oxide (CaO) or burnt lime and lime milk, also known as calcium hydroxide (Ca(OH)₂). If limewater is used (diluted solution of lime milk), please report it as lime milk.
- **Composting** – by choosing “Composting” in either cell “K150” or “K151” additional questions will open in cells “K180” to “K191” asking for composting specifics. Please try to answer to the questions as much as possible with the information at hand, especially the questions about percentage of support material added (cell “K183”) and compost amounts (cells “K187” and “K191”). If compost amount is not measured both before and after the composting process and no estimations can be given, please report either the information before or after composting (whichever one is measured) both in cell ranges “K185” to “K187” and “K189” to “K191”. **Please keep in mind that once again daily data is asked, therefore if only annual data is known, it should be simply averaged to daily.** In such case, please do not exclude the days or months when composting is not working and average the data to a full year (365.25 days). Following background calculations, error checks or choices requiring extra information are used in this subsection:
 - Cell “K182” – composting working throughout the year or seasonally. Composting process should be reported as “seasonal”, if during winter the compost fails to achieve high enough temperature for the composting process to continue (less than 30-40° C). Composting works throughout the year if the process is done indoors or suitable temperature is achieved in windrows even during winter.
 - Cell “K183” – percentage of supporting material added to the sludge. **Please make sure that the percentage provided is of support material mass to sludge mass**, as this value will be used to separate the mass of support material from the mass of sludge for error check in cell “M187”. If only added support material volume is known, please try to estimate the proportions of mass in order to get correct results. If this is not possible, disregard the error check in cell “M187”.
 - Cell “K185” – amount of sludge mixed with support material before composting. If the sludge and support material mix is not measured before composting but both volumes separately are known, the mixed volume should be possible to calculate. If the volumes are not known, but total mass is measured or can be estimated, please leave cells “K185” and “K186” empty and report only the total mass in cell “K187”.
 - **Cell “K187” – total mass of sludge mixed with support material before composting.** If both volume of the sludge mixed with support material (“K185”) and solids content (“K186”) are given, this will be calculated automatically. If the calculated value is incorrect, please check if data in those two cells. As stated previously, if either the volume or solids content is unknown, while the total daily mass is measured, please leave the previous two cells empty to bypass the automatic calculation and report the daily total mass data directly in cell “K187”.
 - Cell “M187” – comparison of total daily mass before composting with previously reported total mass of sludge thickened/dewatered. This error check looks at the previously reported data (depending on processes reported previously either cell “K121” if dewatering was used, cell “K78” if secondary sludge is thickened separately or cell “K69” if mixed sludge was thickened) and compares it to the sludge mass reported before composting. The calculation takes into account the addition of support material (cell “K183”) to calculate the mass of sludge before composting. If all sludge is composted in the WWTP and daily averages are estimated correctly, no major difference should be possible between the two values. This error check can also be marked as “red” if some data needed for the calculation is missing. In such case, please check the cells outlined previously in current paragraph. Following markings are possible:

- “green” if values differ less than 20%,
 - “yellow” if values differ more than 20%,
 - “red” if some data is missing.
- **Cell “K191” – total mass of composted sludge.** If both volume of the composted sludge (“K189”) and solids content (“K190”) are given, this will be calculated automatically. If the calculated value is incorrect, please check if data in those two cells. As stated previously, if either the volume or solids content is unknown, while the total daily mass is measured, please leave the previous two cells empty to bypass the automatic calculation and report the daily total mass data directly in cell “K191”.
- **Cell “M191” – comparison of total daily composted mass with total mass of sludge mixed with support material before composting.** This error check shows the difference between total mass before and after composting. In different scientific articles, the mass loss during composting has been shown between 10-40 % with the average of around 20%. If one of the masses is unknown and therefore both masses are reported as the same (as previously recommended in the SSMA tool), please disregard this error check. Following markings are possible:
 - “green” if loss is between 10% and 40%.
 - “yellow” if outside of aforementioned boundaries.
- **Drying** – by choosing “Drying” in cell “K151” additional questions will open in cells “K153” to “K163”. Please try to answer to the questions as much as possible with the information at hand, especially the questions about sludge masses before (cell “K159”) and after drying (cell “K163”). Following background calculations, error checks or choices requiring extra information are used in this subsection:
 - **Cell “K153” – external sludge added to drying.** Is only asked if previously in subsection 2 (External sludge and other substrates) the cell “K44” is marked as “yes” (accepting external sludge) and cell “K45” (the path of external sludge) is marked as “Other”. If this toggle is marked as “Yes”, more additional questions in cells “K158” and “K159” are opened.
 - **Cell “K159” – total mass of sludge before drying.** Is only asked if “Yes” is selected in cell “K153” reporting external sludge addition to the drying process. This value is calculated based on the values reported in cells “K121” (“Total mass of sludge after dewatering”) and “K158” (“Average amount of sludge from external WWTPs added to drying per day”). If the calculated value is incorrect, please check if data in those two cells. If only part of the sludge is dried, please regard this value or report the sludge mass that is treated differently with a “-” sign (as negative amount) in cell “K158”. In that case the portion of sludge not dried is not taken into account in the SSMA tool any further and if necessary should be reported in a different copy of the audit (it is recommended to make a copy of the audit tool and report sludge treated with different final treatment technologies separately).
 - **Cell “M159” – checks if all data necessary for “K159” calculation is filled.** This error check looks at cells “K121” (“Total mass of sludge after dewatering”) and “K158” (“Average amount of sludge from external WWTPs added to drying per day”). If one of the two cells is empty or has an incorrect (not numerical) answer, this error check is marked “red”. Following markings are possible:
 - “green” if all necessary data for the calculation is filled,
 - “red” if one or both required data fields are empty.
 - **Cell “K163” – total mass of sludge after drying.** If both volume of the sludge after drying (“K161”) and solids content (“K162”) are given, this will be calculated automatically. If the calculated value is incorrect, please check if data in those two cells. As stated previously, if either the volume or solids content is unknown, while the total daily mass is measured, please leave the previous two cells empty to bypass the automatic calculation and report the total mass data directly in cell “K163”.

- Cell “M163” – comparison between the daily mass of sludge before and after drying. If external sludge addition to drying is selected in “K153”, compares the total mass of sludge after drying to the value calculated in “K159” (“Total mass of sludge before drying”). If no external sludge is added, the mass of sludge after dewatering (“K121”) is used in the comparison. As drying should not significantly reduce the sludge mass (solids mass), these two values should be similar. Please make sure that if external sludge addition is selected, the value of external sludge added daily is filled (“K158”) as the error check will be marked “red” in other case. Following markings are possible:
 - “green” if values differ less than 20%,
 - “yellow” if values differ more than 20%,
 - “red” if some external sludge addition is marked but value is missing.
- **Drying and incineration** - by choosing “Drying and incineration” in cell “K151” additional questions will open in both subsection “Drying” (cells “K153” to “K163”) and subsection “Incineration” (cells “K165” to “K178”). Please try to answer to the questions as much as possible with the information at hand, especially the questions about sludge masses before (cell “K159”) and after drying (cell “K163”) and after incineration (cell “K176”). When reporting data concerning to drying, please check the previous subsection for additional information, as that part of the tool is shared with WWTPs only using drying. Following background calculations, error checks or choices requiring extra information are used in this subsection:
 - **Cell “K166” – sludge accepted from other municipal or industrial WWTPs to incineration.** Is only asked if previously in subsection 2 (External sludge and other substrates) the cell “K44” is marked as “yes” (accepting external sludge) and cell “K45” (the path of external sludge) is marked as “Other”. If this toggle is marked as “Yes”, more additional questions in cells “K168” to “K172” are opened.
 - **Cell “K171” – total mass of sludge from your WWTP before incineration.** Is only asked if external sludge addition to the incineration process is marked “Yes” in cell “K166”. If both volume of the sludge before incineration (“K169”) and solids content (“K170”) are given, this will be calculated automatically. If the calculated value is incorrect, please check if data in those two cells. As stated previously, if either the volume or solids content is unknown, while the total daily mass is measured, please leave the previous two cells empty to bypass the automatic calculation and report the total mass data directly in cell “K171”. Please make sure only your own sludge is reported here, as sludge added to the incinerator from outside sources should be reported separately in cell “K168”.
 - Cell “M171” – comparison of sludge mass before incineration and sludge mass after drying. Is only shown if external sludge addition to the incineration process is marked “Yes” in cell “K166”. As only sludge mass from the current WWTP is asked in cells “K169” to “K171”, compares the mass of sludge to the one reported after drying (cell “K163”). As nothing should happen with the sludge between two processes, these amounts should be identical. Following markings are possible:
 - “green” if values differ less than 10%,
 - “yellow” if values differ more than 10%,
 - “red” if data from cells “K163” or “K171” is missing.
 - **Cell “K172” – total mass of sludge before incineration.** Is only calculated if external sludge addition to the incineration process is marked “Yes” in cell “K166”. Adds the values reported in cells “K168” (“Average amount of sludge from external WWTPs added to incineration per day”) and “K171” (“Total mass of sludge from your WWTP before incineration”). If the calculated value is incorrect, please check if data in those two cells. If only part of the sludge is incinerated, please regard this value or report the sludge mass that is treated differently with a “-” sign (as negative amount) in cell “K168”. In that case the portion of sludge not incinerated is not taken into account in the SSMA tool any further and if necessary should be reported in a different copy of the audit (it is

recommended to make a copy of the audit tool and report sludge treated with different final treatment technologies separately).

- Cell “M172” – checks if all data necessary for “K172” calculation is filled. This error check looks at cells “K168” (“Average amount of sludge from external WWTPs added to incineration per day”) and “K171” (“Total mass of sludge from your WWTP before incineration”). If one of the two cells is empty or has an incorrect (not numerical) answer, this error check is marked “red”. Following markings are possible:
 - “green” if all necessary data for the calculation is filled,
 - “red” if one or both required data fields are empty.
- **Cell “K176” – total mass of sludge after incineration.** If both volume of the sludge before incineration (“K174”) and solids content (“K175”) are given, this will be calculated automatically. If the calculated value is incorrect, please check if data in those two cells. As stated previously, if either the volume or solids content is unknown, while the total daily mass is measured, please leave the previous two cells empty to bypass the automatic calculation and report the total mass data directly in cell “K171”.
- Cell “K178” – P-recovery from ash. If the company has technology for phosphorus recovery from the ash or gives away the ash to an outside company for the purpose of phosphorus recovery, please mark this toggle as “Yes”. As phosphorus recovery from incineration ashes is an important source of nutrient recycling and the legislation in the European Union is slowly being changed to reflect that, both the phosphorus recovery potential and the recovery itself is evaluated in the SSMA tool. The selecting either “Yes” or “No” in this toggle directly influences part of the results of the SSMA, therefore please make sure the answer actually reflecting the current state of your WWTPs phosphorus recycling strategy is chosen.

Subsection 8 – Final use of sludge

In this subsection questions about the quality of the treated sludge and the path of the sludge after treatment are presented. The questions in this section do not depend on choices made in the other sections of the tool and are the same regardless of sludge treatment methods.

When filling out cells “K214” to “K219”, please try to estimate the proportions of treated sludge used in different ways during the reported year. If sludge is treated further in another WWTP or given away to a company for either biogas production or phosphorus recovery, please mark it down in cell “K219” (“given to external company for recycling/recovery”). Please make sure the total percentages from cells “K214” to “K219” add up to exactly 100%.

Following choices requiring extra information are used in this subsection:

- **Cell “K207” – sludge meeting regulations for usage in recultivation and greenery.** Depending on your country’s specific regulations, the limits and regulations for direct sludge use may differ. Please toggle “Yes” if the treated sludge exiting your WWTP could potentially be used for recultivation (restoration of landscape, often as landfill or mining area reconstruction) or greenery even if the sludge is not actually used in such ways. Please select “No” if direct usage of treated sludge is forbidden in your legislation (for example based on the size of your WWTP) or if some parameters to use sludge directly are not met.
- **Cell “K208” – sludge meeting regulation for usage in agriculture.** Depending on your country’s specific regulations, the limits and regulations for direct sludge use may differ. Please toggle “Yes” if the treated sludge exiting your WWTP could potentially be used for agriculture, even if the sludge is not actually used that way. In many cases the regulations set for treated sludge usage in agriculture are the strictest ones, so please make sure to check your national legislation before answering. Select “No” if direct usage of treated

sludge is forbidden in your legislation (for example based on the size of your WWTP) or if some parameters to use sludge directly in agriculture are not met.

- **Cell “K209” – certified product produced from the treated sludge.** As treated sludge is considered waste in European legislation, end-of-waste criteria have been set in some countries, that allow the certification of the treated sludge, which labels it as a product and allows WWTPs to sell it as fertiliser. Please choose “Yes” only if the treated sludge (or sludge compost) was certified in the reported period according to your national legislation.
- **Cell “K210” – achieving limit values for heavy metals.** One of the main limiting factors in treated sludge usage are the heavy metal values in the sludge. Please select “Yes” as an answer to this question, if during the reporting period any accredited laboratory analysis showed results above the national limit values for heavy metals (if multiple limit values are provided, please use the strictest ones, usually meant for agricultural use). Only answer “No” to this question, if laboratory analysis were concluded during the reporting period and no heavy metal concentrations were above the limit values in any of the samples.
- **Cell “K211” – achieving limit values for pathogens.** Another limiting factor concerning the direct use of treated sludge is the amounts of pathogens in the treated sludge. Please select “Yes” as an answer if any of the laboratory tests during the reporting period showed problems with achieving hygienised sludge (usually *E.Coli*, *Salmonella* and *Helminths* are tested). Please answer “No” if no pathogens were found in the treated sludge or if thorough thermal treatment or hygienisation was done during the treatment (drying and incineration are usually considered enough).
- **Cell “M213” – checks if final usage of sludge or ash amounts to 100%.** This error check sums up the reported percentages in the cell range “K214” – “K219” and shows a “green” marking if the sum is exactly 100%. If this error check is not marked “green”, please look over the values reported. Following markings are possible:
 - “green” if the sum of sludge or ash usage amounts to exactly 100%,
 - “red” if the sum of sludge or ash usage is not exactly 100%.

When all the cells are filled in the “Input” section, please move to the “Laboratory data” section and fill in the necessary information there. After both sections are filled, then the button “Process data and create audit results” should be pushed for data processing. After that results could be found from sections “Figures and results” and “Summary”.

2.2 Section 2 – Data sheet for water and sludge analysis on sheet “Laboratory data”

General rules

As mentioned before in both the SSMA tool and this document, please fill in the rows 11-13 in “Laboratory data” sheet right after filling in the rows 10-24 in the “Input” sheet in order to allow the tool to calculate sludge age, sludge amounts and other calculations needing influent data.

All the calculations in the tool are made with the value of BOD_5 , please use the following relation when BOD_7 is measured in order to convert the data: $BOD_5 = BOD_7 / 1.17$ (insert only the value of BOD_5 into the tool. For all inquired data yearly average values should be submitted, also please note that the submitted value has same unit as required in the table.

The laboratory data section consists of two subsections: “Basic wastewater characteristics” and “Sludge sample analysis”. Some of the questions in this subsection open with specific choices made in the SSMA so please make sure everything in the “Input” sheet is reported correctly in order to open the correct rows for laboratory data reporting.

Subsection 1 – Basic wastewater characteristics

Five basic wastewater parameters are asked in this section after different points of treatment – chemical oxygen demand (COD), biological oxygen demand during 5 days (BOD₅), total nitrogen (TN), total phosphorus (P_{tot}) and suspended solids (SS) concentrations. Pollutant loads are calculated based on the average daily flow rate reported in cell “K18” in the “Input” section. Reject water flow rate is calculated based on the data reported in the “Digestion” and “Dewatering” subsections (assumption has been made that only WWTPs with anaerobic digestion have separate reject water treatment. If your WWTP doesn’t measure all of the asked concentrations regularly, we would ask to at least measure them once if possible and fill out that data. While annual average data is more precise, even point-sample data would allow the SSMA tool to make calculations and give some of the results, which would otherwise be left empty. **Especially important are the cells “C11”, “E11”, “E12”, “K11” and “K12”, which are directly used in calculations in the “Input” sheet.** Following points of measurement are asked for the tool:

- **Row 11 – influent.** Refers to influent wastewater to the WWTP, analysis should be done before treatment to show incoming pollution loads to the WWTP.
- **Row 12 – after primary clarification.** Is only asked if primary clarification is reported in cell “K21” in the “Input” sheet. Refers to the wastewater after primary clarification, before biological treatment starts. If your WWTP does not measure this point regularly, we would recommend doing extra analysis if possible, to fill out this section. In that case the data reported here would not be annual average, while any information is still better than none and helps the tool provide more specific results.
- **Row 13 – effluent.** Refers to the wastewater discharged from the WWTP, analysis should be done after all treatment steps (including secondary clarification and post-treatment if used in the WWTP).
- **Row 14 – reject water before treatment.** Is only asked if reject water from dewatering has a separate treatment reported in cell “K122” in the “Input” sheet and measurement point in cell “K123” is either “From before and after” or “Only before treatment”. These values are not used in calculation, while if some results need to be evaluated manually (outside consultation) these values might provide important background information. Flow rate and loads are calculated based on the amount of water reported in the sludge after digestion compared to the amount of water reported in the sludge after dewatering (cells “K103”, “K104”, “K119” and “K120” in the “Input” sheet). If any of these cells is empty, the reject water flow rate and therefore volumes of pollutants can’t be calculated.
- **Row 15 – reject water after treatment.** Is only asked if reject water from dewatering has a separate treatment reported in cell “K122” in the “Input” sheet and measurement point in cell “K123” is either “From before and after” or “Only after treatment”. These values are not used in calculation, while if some results need to be evaluated manually (outside consultation) these values might provide important background information. Flow rate and loads are calculated based on the amount of water reported in the sludge after digestion compared to the amount of water reported in the sludge after dewatering (cells “K103”, “K104”, “K119” and “K120” in the “Input” sheet). If any of these cells is empty, the reject water flow rate and therefore volumes of pollutants can’t be calculated.

Subsection 2 – Sludge sample analysis

Five basic sludge parameters – COD, TN, P_{tot} , dry matter and burn residue – and concentrations of seven important heavy metals (based on HELCOM recommendations (HELCOM Land-based Pollution Group 2014)) – Cd, Pb, Cr, Cu, Zn, Ni and Hg – are asked in this section after different points of treatment. **It is important to not that only the data after the last treatment step is strictly necessary** while intermediate data could be useful to evaluate the flows of pollutants in the WWTP especially if manual evaluation by an outside consultant is planned. The pollutant loads in this section are calculated based on the daily amount of sludge (column “C”), which is automatically calculated based on the data reported in the “Input” sheet. It is again important to note that specific rows in this subsection open based on the choices made in the “Input” sheet, showing only data points relevant to the specific WWTP. Following points of measurement are asked in the tool:

- Row 23 – secondary sludge after thickening. Is only asked if secondary sludge is thickened separately (no primary clarification reported in cell “K21” in the “Input” sheet or if answer “No” is selected in cell “K62” in the “Input” sheet). The sludge amount (cell “C23”) is transferred from cell “K78” in the “Input” sheet. If the transferred data is incorrect, please check that the value in that cell is correct, more information about that cell can be found in the previous sections (Subsection 3 – Thickening) of the current guidelines document.
- Row 24 – mixed sludge after thickening. Is only asked if primary clarification is reported in cell “K21” in the “Input” sheet. Refers to the mix of primary and secondary sludge transported to subsequent sludge treatment steps. The sludge amount (cell “C24”) is transferred from either cell “K69” in the “Input” sheet if mixed sludge is thickened separately or calculated as a sum of primary and secondary sludge amounts (sum of cells “K59” and “K78” in the “Input” sheet). If the transferred data is incorrect, please check that the value in those cells are correct, more information about those cells can be found in the previous sections (Subsection 3 – Thickening) of the current guidelines document.
- Row 25 – sludge after dewatering. Is only asked if dewatering is selected in cell “K112” in the “Input” sheet. The sludge amount (cell “C25”) is transferred from cell “K121” in the “Input” sheet. If the transferred data is incorrect, please check that the value in that cell is correct, more information about that cell can be found in the previous sections (Subsection 5 – Dewatering) of the current guidelines document.
- Row 26 – sludge after drying. Is only asked if either “Drying” or “Drying and incineration” are selected in cell “K151” in the “Input” sheet. The sludge amount (cell “C26”) is transferred from cell “K163” in the “Input” sheet. If the transferred data is incorrect, please check that the value in that cell is correct, more information about that cell can be found in the previous sections (Subsection 7 – Further sludge treatment) of the current guidelines document.
- Row 27 – sludge (ash) after incineration. Is only asked if “Drying and incineration” is selected in cell “K151” in the “Input” sheet. The sludge amount (cell “C27”) is transferred from cell “K176” in the “Input” sheet. If the transferred data is incorrect, please check that the value in that cell is correct, more information about that cell can be found in the previous sections (Subsection 7 – Further sludge treatment) of the current guidelines document.
- Row 28 – sludge mixed with support material before composting. Is only asked if “Composting” is selected in either cell “K150” or “K151” in the “Input” sheet. The sludge amount (cell “C28”) is transferred from cell “K187” in the “Input” sheet. If the transferred data is incorrect, please check that the value in that cell is correct, more information about that cell can be found in the previous sections (Subsection 7 – Further sludge treatment) of the current guidelines document.
- Row 29 – sludge after composting. Is only asked if “Composting” is selected in either cell “K150” or “K151” in the “Input” sheet. The sludge amount (cell “C29”) is transferred from cell “K191” in the “Input” sheet. If the transferred data is incorrect, please check that the value in that cell is correct, more information about that cell can be found in the previous sections (Subsection 7 – Further sludge treatment) of the current guidelines document.

- Row 30 – sludge after lime stabilisation. Is only asked if “Lime stabilisation” is selected in cell “K150” in the “Input” sheet. The sludge amount (cell “C30”) is transferred from cell “K202” in the “Input” sheet (as annual data is reported the sludge amount is divided by 365). If the transferred data is incorrect, please check that the value in that cell is correct, more information about that cell can be found in the previous sections (Subsection 7 – Further sludge treatment) of the current guidelines document.
- Row 31 – sludge after humification. Is only asked if “Humification” is selected in cell “K150” in the “Input” sheet. The sludge amount in kg TS d⁻¹ (cell “C31”) is calculated based on the annual amount of humified product from cell “K198” in the “Input” sheet (as annual data is reported the sludge amount is divided by 365) and **dry matter concentration in cell “J31” in the “Laboratory data” sheet**. If the transferred data is incorrect, please check that the values in those cells are filled and correct, more information about the cells in the “Input” sheet can be found in the previous sections (Subsection 7 – Further sludge treatment) of the current guidelines document.

When all the cells are filled in both the “Input” and “Laboratory data” sheets, please move back to the “Input” sheet and press the button “Process data and create audit results” to evaluate the reported data and create results. After that results can be found on sheets “Figures and results” and “Summary”. **If something in the reported data is changed, the “Process data and create audit results” button can be pressed again to update the results.** The button should work for partially filled tools as well, although with missing data the results shown might be incorrect.

2.3 Section 3 – Figures and results – regional comparison on sheet “Figures and results”

General rules

After the button “Process data and create audit results” has been pressed in the “Input” sheet regional comparisons should become available in the “Figures and results” sheet. The comparisons are based on the key figures collected from 66 WWTPs in the Baltic Sea region during the IWAMA project. Benchmarks created from the key figure data have been published as a separate document, which can be found on the IWAMA webpage (“Key Figure Data for Sludge Benchmark”) (Raudkivi et al. 2018).

Most of the figures presented in this section use the collected key figure data as background information on which your WWTP information is presented (Figure 6). This should allow each of the WWTPs see how they fit into the Baltic Sea region median values for influent wastewater characteristics and heavy metal concentrations in the treated sludge or how they have performed at specific treatment stages compared to other WWTPs. Please bear in mind that the number of values included in the background data for each of the figures can be different as WWTPs included in the data collection had varying sizes and technologies. Therefore, for example not all WWTPs in the data collection measured suspended solids concentration in the influent, had anaerobic digestions and biogas utilisation or sent their treated sludge for heavy metal analysis. The specific number of WWTPs included in the background data is given in this document for each of the figures present in the SSMA tool.

Similarly, not all results and figures might be applicable and therefore filled for the reported WWTP – if the WWTP doesn’t use specific technology the results cannot be shown. If a figure should be filled but is empty or missing the red stiped line indicating your results, there could be a problem with the reported data. Please check the specific figure explanation for more information and press **“Process data and create audit results”** button if anything is changed in the “Input” or “Laboratory data” sheets. If problems persist, please use the contact information provided in the “Disclaimer” sheet and let us know.

Most of the figures in the SSMA tool can be read the same way – an example on that has been also given under Figure 6. In those cases, the results should be compared to the 50th percentile (median), while the nature of the parameter should make it clear whether higher or lower results are “better” for the WWTP. In the following section some explanations and extra information is presented for each of the figures used in the SSMA tool as well, as some of the specifics of a certain figures can be difficult to understand.

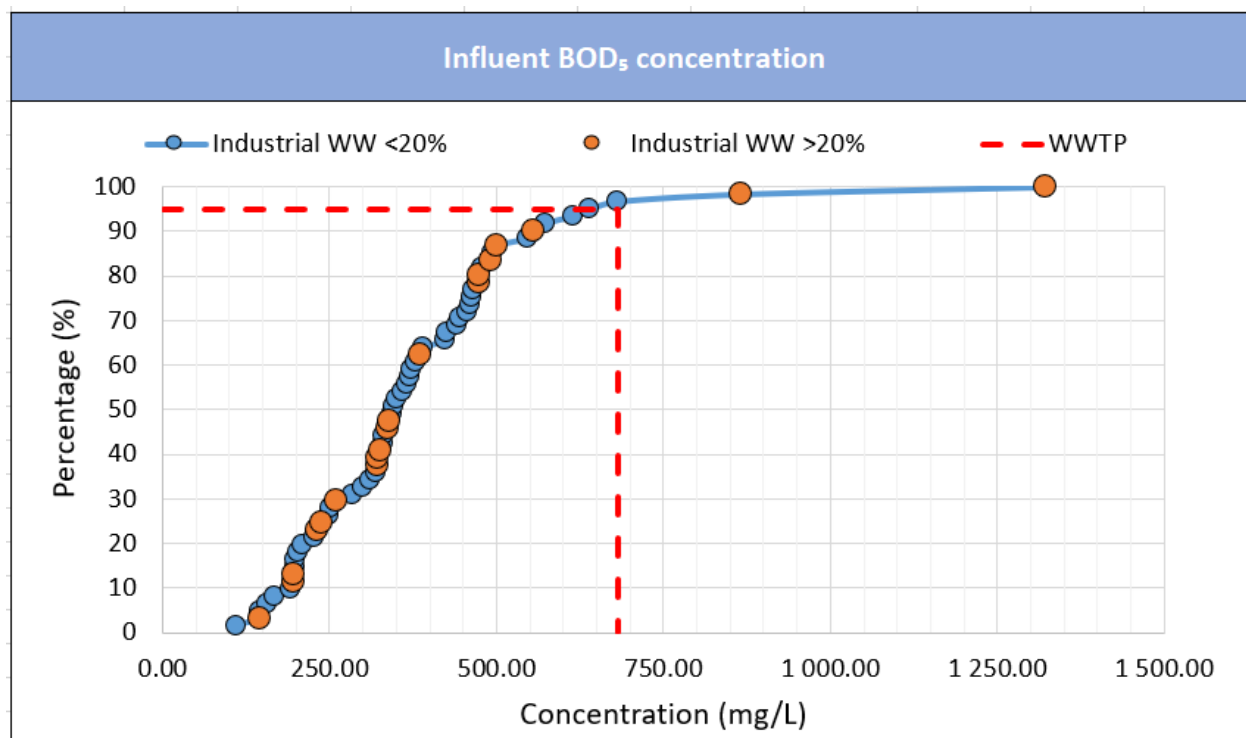


Figure 6 - Example of a figure using data collected in the IWAMA project key figure collection as a background (61 WWTPs). The title of the figure is presented on the top of the figure with a blue background. All regional comparison figures are shown on a cumulative frequency graph with percentages referring to total number of WWTPs in the sample. In this figure the blue markers represent all WWTPs with lower than industrial WW inflow lower than 20% (by volume) with orange markers are shown for WWTPs having higher than 20% of their influent coming from industrial sources. The result of the audited WWTP is shown as a red striped line – in this case showing influent BOD₅ concentration of 681 mg L⁻¹, which is higher than for 95% of the WWTPs in the region. This can also be phrased as the WWTP being in the 95th percentile with the influent BOD₅ concentration.

Once again, please remember that we issue no guarantee on the correctness and completeness of the information and results in this tool. In case of interesting information or discoveries made using the SSMA concept or tool, we recommend consulting an outside expert before making any decisions with potentially financial implication.

In the following subsections all the figures are alphabetised for easier referencing and understanding. Letters are chosen instead of numbers in order not to mix the figures in the SSMA tool with the figures presented in this specific document. It is important to note, that these references (for example Figure A) are not used in the SSMA tool, where figures are presented only with the title as indicated on Figure 6 above.

Subsection 1 – Basic wastewater characteristics

This subsection consists of five figures for the most common and important influent parameters and three figures connected to the sludge age. Most of these figures are cumulative frequency graphs based on the key figure

collection, while one of the graphs (“Secondary sludge production compared to optimal sludge age”) is based on an industry standard calculation and doesn’t have comparison data on it.

The figures for influent parameters are mainly presented for background knowledge, as the results don’t indicate any specific problems, and might rather show the basic reasons why the specific WWTP might achieve better or worse values in other categories. It is important to mention, that the N/BOD₅ and P/BOD₅ ratios used in the “Summary” sheet for influent evaluation are not presented in the “Figures and results” sheet, while the figures are included in the next section of this guidelines document for additional background data.

Overall very high influent parameter concentrations are usually due to industrial inflows, very low concentrations can be influenced by industrial inflow but are very often caused by combined stormwater runoff systems. As the Baltic Sea Region is considered as humid climate with quite high annual rainfall (mean annual precipitation in the entire region over 600 mm (BACC Author Team 2008)), the diluting effect of stormwater in the combined system can be quite significant increasing the treatment volumes, lowering HRT and etc. If compared to regional median values your influent concentrations of different parameters are significantly lower and combined stormwater collection is used, we recommend looking into the possible effects by conducting a thorough study or hiring an outside consultant.

This subsection has the following figures:

- **Figure A – influent BOD₅ concentration.** Based on the results from 61 WWTPs. This figure was also used as an example of cumulative frequency graphs on Figure 6. The figure differentiates background information based on the volume of industrial wastewater accepted in the WWTPs, as WWTPs with high industrial inflow can have significantly different values of pollutants and nutrients in the influent.

The results for your WWTP can only be seen on the figure if cell “E11” in the “Laboratory data” sheet and “K18” (“Average daily flow rate”) in the “Input” sheet are filled. If any information is changed in the “Input” or “Laboratory data” sheet, please press “Process data and create audit results” button again to update the figure.

Higher BOD₅ concentrations mean more easily degradable organic content in the influent, which can result to easier biological treatment (depends on N/BOD₅ and P/BOD₅ ratios), higher sludge and subsequently biogas production. At the same time depending on the source of the higher organic load, this could also mean extra problems with equipment, bigger expenses on maintenance and other possible negative influences. WWTPs with low influent BOD₅ concentrations might struggle with achieving high efficiency biological nitrogen and phosphorus removal without substantial external organic carbon (methanol) dosing.

The regional median value based on the key figure collection was about 345 mg L⁻¹, with 238 mg L⁻¹ as the 25th percentile and 462 mg L⁻¹ as the 75th percentile. Very high BOD₅ concentrations (over 700 mg L⁻¹) were only present in WWTPs accepting large industrial inflows.

- **Figure B – influent COD concentration.** Based on the results from 57 WWTPs. The figure differentiates background information based on the volume of industrial wastewater accepted in the WWTPs, as WWTPs with high industrial inflow can have significantly different values of pollutants and nutrients in the influent.

The results for your WWTP can only be seen on the figure if cell “C11” in the “Laboratory data” sheet and “K18” (“Average daily flow rate”) in the “Input” sheet are filled. If any information is changed in the “Input” or “Laboratory data” sheet, please press “Process data and create audit results” button again to update the figure.

As BOD₅ concentration is also part of the COD concentration, BOD₅/COD ratio is usually considered more important than raw COD values. High BOD₅/COD ratios show high biodegradability of wastewater meaning it’s suitable for biological treatment (usually considered above 0.5). Low BOD₅/COD ratios (usually considered under 0.3) are usually connected to industries, where non-biodegradable fraction is produced (oil, chemicals, pharmaceuticals and etc). Therefore, very high or low COD concentrations should not be a problem if the BOD₅/COD ratio is in normal boundaries (usually considered 0.3 to 0.8). Scientific research

and benchmarking has also show that WWTPs receiving diluted wastewater (with low COD concentrations) have an overall higher specific energy consumption as higher volume of water needs to be aerated (Vaccari et al. 2018).

The regional median value based on the key figure collection was about 771 mg L⁻¹, with 605 mg L⁻¹ as the 25th percentile and 1065 mg L⁻¹ as the 75th percentile. Similar to BOD₅, very high COD concentrations (over 1600 mg L⁻¹) were only present in WWTPs accepting large industrial inflows.

- **Figure C – influent TN concentration.** Based on the results from 55 WWTPs. The figure differentiates background information based on the volume of industrial wastewater accepted in the WWTPs, as WWTPs with high industrial inflow can have significantly different values of pollutants and nutrients in the influent.

The results for your WWTP can only be seen on the figure if cell “G11” in the “Laboratory data” sheet and “K18” (“Average daily flow rate”) in the “Input” sheet are filled. If any information is changed in the “Input” or “Laboratory data” sheet, please press “Process data and create audit results” button again to update the figure.

As nitrogen is a limiting nutrient in the water systems (although with smaller impact than phosphorus), reducing nitrogen concentrations is one of the main aims of wastewater treatment. Therefore, high nitrogen concentrations in the influent usually mean bigger expenditures in biological wastewater treatment, either for aeration or organic carbon dosing. The effect of higher nitrogen concentrations depends a lot on N/BOD₅ ratio as denitrification uses organic carbon in the process of reducing nitrogen (ratio under 0.25 should not need any external organic carbon dosing). In case of low nitrogen and high BOD₅ concentrations (industrial inflow), more primary sludge can be removed as the lack of organic carbon during biological treatment should not be a problem.

The regional median value based on the key figure collection was about 68 mg L⁻¹, with 55 mg L⁻¹ as the 25th percentile and 85 mg L⁻¹ as the 75th percentile. Very high nitrogen concentrations (over 100 mg L⁻¹) were reported by both WWTPs with and without high industrial inflow while the difference between highest reported values and median values were not as large (135 mg L⁻¹ and 68 mg L⁻¹ for TN, while 1323 mg L⁻¹ and 345 mg L⁻¹ for BOD₅; 2637 mg L⁻¹ and 771 mg L⁻¹ for COD).

- **Figure D – influent P_{tot} concentration.** Based on the results from 59 WWTPs. The figure differentiates background information based on the volume of industrial wastewater accepted in the WWTPs, as WWTPs with high industrial inflow can have significantly different values of pollutants and nutrients in the influent.

The results for your WWTP can only be seen on the figure if cell “I11” in the “Laboratory data” sheet and “K18” (“Average daily flow rate”) in the “Input” sheet are filled. If any information is changed in the “Input” or “Laboratory data” sheet, please press “Process data and create audit results” button again to update the figure.

Phosphorus is considered the most crucial limiting factor in water ecosystems with excess amounts contributing directly to eutrophication, therefore phosphorus removal either by biological or chemical means is a key element in wastewater treatment. As with nitrogen the most important factor when considering the phosphorus concentrations in the influent is the P/BOD₅ ratio – when the ratio is over 0.01, chemical precipitation is considered a necessity. Very high phosphorus concentrations and P/BOD₅ ratios result to more chemical dosing, which can also influence sludge treatment as precipitated phosphorus minerals are removed as part of the sludge and contribute to the total sludge mass while being mostly inert to different sludge treatment processes. High chemical phosphorus removal can for example reduce biogas production per loaded kg TS as the organic biodegradable carbon fraction in the sludge can be 20-30% lower. High precipitation can also negatively influence thickening and dewatering (significant difference when precipitation uses aluminium salts) (Derco 2016).

The regional median value based on the key figure collection was about 9.43 mg L⁻¹, with 7.1 mg L⁻¹ as the 25th percentile and 13.6 mg L⁻¹ as the 75th percentile. Very high phosphorus concentrations (over 15 mg L⁻¹) were reported by both WWTPs with and without high industrial inflow (highest being 22 mg L⁻¹).

- **Figure E – influent SS concentration.** Based on the results from 53 WWTPs. The figure differentiates background information based on the volume of industrial wastewater accepted in the WWTPs, as WWTPs with high industrial inflow can have significantly different values of pollutants and nutrients in the influent.

The results for your WWTP can only be seen on the figure if cell “K11” in the “Laboratory data” sheet and “K18” (“Average daily flow rate”) in the “Input” sheet are filled. If any information is changed in the “Input” or “Laboratory data” sheet, please press “Process data and create audit results” button again to update the figure.

Suspended solids include organic carbon, phosphorus and nitrogen and therefore larger WWTPs use primary clarification in order to remove most of the suspended solids before biological treatment. While this reduces the load of nitrogen and phosphorus on biological treatment and increase biogas production potential (organic carbon in suspended solids is considered more biodegradable and with higher biogas potential), it can also deprive biological treatment of organic carbon and create the need for external dosing. High suspended solids concentration can therefore potentially increase primary sludge and biogas production. At the same time, some WWTPs use grinders or macerators in the sewage system to avoid blockages and manual cleaning of pumping stations, also resulting in high SS concentrations in the influent. In those cases the suspended solids include a large proportion of inert materials and plastics, which can influence subsequent treatment negatively (often removed beforehand using sand filters with surface scrapes).

The regional median value based on the key figure collection was about 330 mg L⁻¹, with 256 mg L⁻¹ as the 25th percentile and 410 mg L⁻¹ as the 75th percentile. Very high suspended solids concentrations (over 500 mg L⁻¹) were more common among WWTP without high industrial inflow (highest being 787 mg L⁻¹), while some industrial wastewater (food production for example) can increase it significantly as well (highest being 620 mg L⁻¹).

- **Figure F – simple sludge age calculated.** Based on results from 49 WWTPs. As sludge age is both asked and calculated in the SSMA tool, two different sludge age comparison graphs are included in the “Figures and results” sheet (Figure F for calculated and Figure G for reported sludge age). As calculated sludge age does not include sludge generation from chemical phosphorus precipitation, these two graphs can be quite different. If sludge is not measured regularly in the WWTP, this figure should be considered more important.

The results for your WWTP can only be seen on the figure if cell “K35” (“Calculated simple t_{SS} in the biological treatment”) in the “Input” sheet is filled. If this value is not calculated, please see Equation 1 on page 6 and check the cells used as basis of the calculation accordingly. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the figure.

Although the optimal sludge age in the biological treatment depends on many parameters such as average wastewater temperature, nitrogen concentration, sludge treatment technologies, the optimal sludge age for WWTPs using anaerobic digestion is often considered to be 15 days. Higher sludge age results in lower biogas potential, as some of the easily degradable organic content in sludge starts degrading already in the biological treatment tank (is used for denitrification). This can result in more stabilised sludge and higher nitrogen removal without external organic carbon dosing, beneficial to WWTPs without digestion. The sludge age has a high seasonal fluctuation as higher sludge age is often needed in the Baltic Sea region during winter to maintain sufficient biological mass (especially for nitrification). Higher sludge ages can also influence settling, thickening and dewatering processes therefore sludge age should be monitored frequently.

The regional median value based on the key figure collection was about 17.8 days, with 11.5 days as the 25th percentile and 30 days as the 75th percentile.

- **Figure G – simple sludge age reported.** Based on results from 49 WWTPs. As sludge age is both asked and calculated in the SSMA tool, two different sludge age comparison graphs are included in the “Figures and results” sheet (Figure F for calculated and Figure G for reported sludge age). As calculated sludge age does not include sludge generation from chemical phosphorus precipitation, these two graphs can be quite different and should be considered equally. If sludge age in the WWTP is monitored regularly, this figure should be considered more important.

The results for your WWTP can only be seen on the figure if cell “K34” (“Average t_{ss} in the biological treatment”) in the “Input” sheet is filled. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the figure.

The background data for this figure is based on the calculated sludge age from the information gathered in the key figure collection (same as for Figure F). The explanations about the importance of sludge age, optimal range and background data values can be read under the previous figure.

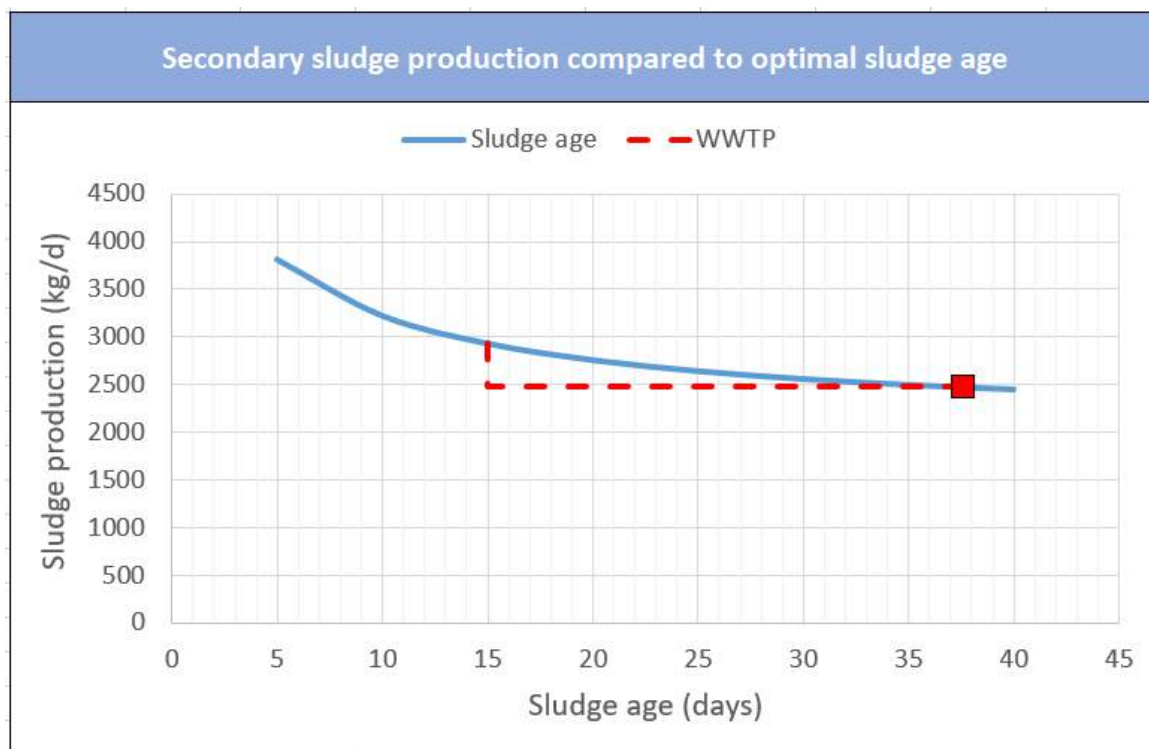


Figure 7 – Example of the sludge age influence on secondary sludge production graph. In this example, the calculated sludge age for the WWTP was 37.6 days, marked with the red rectangle. The blue line shows calculated secondary sludge production on different sludge ages (calculated for 5-day intervals: with sludge age of 5, 10, 15 etc days). The red striped line shows difference with the optimal sludge age of 15 days. Based on this graph, the secondary sludge production from carbon removal is about 2470 kg d⁻¹ with the sludge age of 37.6 days while with optimal sludge age of 15 days it would be around 2930 kg d⁻¹. This means about 15% lower secondary sludge generation, which also results in lower biogas potential as this reduction is mainly caused by the loss of easily degradable organic matter.

- Figure H – secondary sludge production compared to optimal sludge age.** This figure is not based on background data collected during the key figure collection, but calculations presented in the German standard ATV-DVWK-A 131E (ATV-DVWK Standard 2000) (Equation 4 on page 9). Based on the reported data for the WWTP, potential secondary sludge production is calculated with different sludge ages, showing the curve of secondary sludge mass reduction (and easily degradable organic content reduction) caused by sludge age increase. Only daily sludge production from carbon removal is calculated, as based on the standard neither the sludge from biological nor chemical phosphorus removal is significantly dependant of sludge age. The sludge age marked on the graph is also calculated, not based on the reported value. The example on what this figure should look like with explanations is presented on Figure 7.

If this figure is empty or missing the red striped line, there could be a problem with the reported data. Please look at the Equation 4 explanation and check the corresponding cells outlined. If the calculations for sludge age (“K35”) and secondary sludge production (“K69” or “K78”) on the “Input” sheet are present and the figure is still empty, please try re-entering any of the data in either mixed or secondary sludge thickening subsections on the “Input” sheet, which should result in the figure updating. If problems persist, please use the contact information provided in the “Disclaimer” sheet and let us know.

Subsection 2 – Thickening and dewatering

This subsection consists of three figures about thickening and dewatering efficiencies. All of the figures are cumulative frequency graphs based on the key figure collection. The figures for both thickening and dewatering efficiencies are presented for the comparison of achieved total solids with other WWTPs in the region. Please bear in mind that polymer dosing amounts are not taken into account on the figures. As some WWTPs during the creation of the SSMA concept and tool have let us know they refrain from achieving too high TS content in sludge due to the limitations of subsequent sludge treatment processes (the optimal TS for some drying equipment is for example 20-25% TS), higher achieved TS content may not always be better in all situations. When comparing your results with the provided background data, please bear in mind the specifics of you WWTP.

As different thickening and dewatering equipment can also influence achieved TS greatly, the equipment type is marked on the first two figures in this subsection. Separate trendlines for each of the different equipment types was unfortunately not possible to provide as many technologies had too few results to show separately. On the third figure background is given based on the sludge treatment before dewatering, with separate arrays for WWTPs using dewatering after thickening and anaerobic digestion.

This subsection has the following figures:

- Figure I – TS achieved during thickening compared to used technologies.** Based on results from 49 WWTPs. As previously mentioned, the specific technologies used for thickening are marked in the background data. Unspecified group refers to the WWTPs who didn't report the type of equipment used. As many WWTPs use multiple steps of thickening (separate technologies for primary and secondary/mixed sludge thickening), this figure uses the data from final thickening step (usually secondary/mixed thickening), while subsequent dewatering (used mostly in smaller WWTPs) is counted on the next figure. Once again, the effect of polymer dosing can't be seen from this figure as only achieved TS is accounted, not the specific way of achieving it.

The results for your WWTP can only be seen on the figure if cell "K68" ("Solids content in thickened mixed sludge") or cell "K77" ("Solids content in thickened secondary sludge") in the "Input" sheet is filled. If any information is changed in the "Input" sheet, please press "Process data and create audit results" button again to update the figure.

Sludge from the biological treatment is considered to be around 99% water, having very large total volume and mass. During thickening the water content can be lowered significantly, in very broad terms thickening the sludge to 3% solids reduces both the volume and mass of sludge more than 3 times (compared to unthickened sludge with TS below 1%). This also reduces the volume required for sludge treatment, reduces the transportable volume and mass (important for landfilling or external treatment), reduces the amount of heat required for digestion. Overall the higher TS content can be achieved the better the thickening is considered.

The regional median value based on the key figure collection was about 5% TS, with 3.3% TS as the 25th percentile and 5.7 % TS as the 75th percentile. As expected, gravity thickening with no following mechanical thickening achieved the lowest TS content. No apparent correlations were seen between different types of mechanical thickening equipment (amount of data collected was not large enough for thorough analysis). Unfortunately, the WWTPs with the two highest TS values used unspecified equipment, which makes it difficult to evaluate the conditions and equipment used (can potentially be dewatering values reported in the wrong section).

- Figure J – TS achieved during dewatering compared to used technologies.** Based on the results from 37 WWTPs. As previously mentioned, the specific technologies used for dewatering are marked in the background data. Unspecified group refers to the WWTPs who didn't report the type of equipment used. The background information on this figure does not differentiate between WWTPs using dewatering after thickening or anaerobic digestion, those results are presented on Figure K. Once again, the effect of polymer dosing can't be seen from this figure as only achieved TS is accounted, not the specific way of achieving it.

As the maximal dewaterability depends on the specific sludge, WWTPs having problems with their dewatering efficiency might consider a maximal dewaterability test, which shows the achievable values for the specific sludge.

The results for your WWTP can only be seen on the figure if the WWTP uses dewatering. If dewatering is marked with “No” in cell “K112” in the “Input” sheet or the value in cell “K120” (“Solids content in dewatered sludge”) is missing, only background data will be shown on this figure. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the figure.

Like thickening, the dewatering process lowers the amount of water content in the sludge, increasing the total solids content. This greatly reduces the volume and mass of sludge, which is necessary for both transportation and further treatment. As most of the WWTPs in the key figure collection used centrifuges for dewatering, the amount of data collected for other types of equipment was not large enough for thorough analysis. That being said, the highest efficiency reported was achieved with a chamber filter press (over 7% higher than the next reported result), while lime was added to the sludge before dewatering.

The regional median value based on the key figure collection was about 22% TS, with 18.5% TS as the 25th percentile and 24.9 % TS as the 75th percentile.

- **Figure K – effect of digestion on achieved TS with dewatering.** Based on the results from 37 WWTPs, 17 WWTPs for undigested sludge and 20 WWTPs for digested sludge. The figure differentiates background information based on previous treatment – dewatering following anaerobic digestion is separate from dewatering following thickening. This figure does not take into account the specific technology used (see Figure J for that) or polymer dosing.

The results for your WWTP can only be seen on the figure if the WWTP uses dewatering. If dewatering is marked with “No” in cell “K112” in the “Input” sheet or the value in cell “K120” (“Solids content in dewatered sludge”) is missing, only background data will be shown on this figure. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the figure.

The TS content achievable with dewatering differs based on the sludge quality. For example, digested sludge has different particle size distribution (most abundant particle size range of 75-100 µm in undigested sludge, 15-35 µm in sludge digested for 24 days moving towards 10-15 µm during longer digestion (Barbusinski and Koscielniak 1997)) it results in better compressibility of sludge flocs. As digestion affects many sludge parameters, overall achieved TS content with dewatering should be higher.

The regional median value based on the key figure collection for undigested sludge was about 20.5% TS, with 17% TS as the 25th percentile and 22.5% TS as the 75th percentile, while the regional median for digested sludge was about 22%, with 20.25% TS as the 25th percentile and 24.9 % TS as the 75th percentile. On average about 2% higher TS content was achieved with dewatering of digested sludge compared to undigested, while as mentioned previously, other affecting parameters such as equipment type and polymer dosing was not taken into account here.

Subsection 3 – Anaerobic digestion and biogas production

This subsection consists of four figures about anaerobic digestion and biogas production. All of the figures are cumulative frequency graphs based on the key figure collection. This subsection is only open and figures shown if “Yes” is marked in cell “K84” (“Is digestion of the sludge applied in the WWTP”) in the “Input” sheet.

While Figure L (“Biogas production per TS loaded to digester”) is separate from the others, Figures M to O (“Biogas production per WWTP PE”) show the same value with different background information – Figure M shows all the data on the background, Figure N the WWTPs not accepting external substrates to digestion and Figure O the WWTPs with external substrates addition. As co-digestion of waste activated sludge and other organic waste products (biodegradables) is recommended and even necessary to achieve an energy neutral or energy positive WWTP,

reported data is shown on each of the three figures. This allows the audited WWTP to compare achieved results with all the WWTPs, WWTPs still using mono-digestion and WWTPs using co-digestion, providing a larger overall picture.

All of the figures in this subsection deal with biogas production. Figures and data for biogas utilisation and energy production are shown in Subsection 4 – Energy production from biogas.

This subsection has the following figures:

- **Figure L – biogas production per TS loaded to digester.** Based on the results from 19 WWTPs. The value shown on the figure is calculated based on daily average flow into the digester and reported daily biogas production. This figure does not take into account differences in the operation of anaerobic digestion (for example HRT, sequential digestion, intermittent hydrolysis). Please keep in mind TS content does not directly refer to organic content in the loaded sludge (OLR), results based on the OLR could differ greatly as the TS/VSS ratio in the loaded sludge depends on many different operational parameters. Although biogas production per organic content loaded is a more common parameter to describe anaerobic digestion, due to the fact many contributing WWTPs did not measure or report the data in the key figure collection, background information could not be provided for comparison.

The results for your WWTP can only be seen on the figure if cells “K101” (“Average daily amount of inflow to the digester”) and “K106” (“Biogas production”) in the “Input” sheet are filled. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the figure.

Biogas production per loaded TS shows the amount of biogas produced from a kilogram of loaded sludge solids. As sludge can have varying proportions of organic and inert material, WWTPs with high chemical phosphorus precipitation may achieve lower results in this comparison. Optimal biogas production for municipal WWTP is considered 0.3 to 0.4 m³ kg⁻¹ TS d⁻¹. Biogas production could be substantially increased by co-digestion, which not only increases biogas production as more organic content is loaded, but also accelerates methane production, providing more biogas from sludge as well (Koch et al. 2016). While co-digestion is widely recommended, this might not be possible for each WWTP depending on the national legislations and availability of the material.

The regional median value based on the key figure collection was about 0.32 m³ kg⁻¹ TS d⁻¹, with 0.28 m³ kg⁻¹ TS d⁻¹ as the 25th percentile and 0.38 m³ kg⁻¹ TS d⁻¹ as the 75th percentile. These numbers refer to total biogas production, not methane (CH₄) production. Based on anaerobic digestion specific parameters the average methane content in the biogas should be around 55 to 65%.

- **Figure M – biogas production per WWTP PE (by COD load) all.** Based on the results from 27 WWTPs, out of which 18 WWTPs didn’t add additional substrates and 9 WWTPs did. The value shown on the figure is calculated based on WWTP PE_{COD,120} value (more information on page 5) and reported daily biogas production. This figure does not take into account differences in the operation of anaerobic digestion (for example HRT, sequential digestion, intermittent hydrolysis).

The results for your WWTP can only be seen on the figure if cells “K17” (“WWTP capacity by COD”) and “K106” (“Biogas production”) in the “Input” sheet are filled. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the figure.

Biogas production by WWTP PE_{COD,120} ties together energy production with WWTP size to show the possibilities of energy neutral or energy positive wastewater treatment. As wastewater treatment (especially aeration) is on average the most energy-demanding process in a WWTP (Gurung, Tang, and Sillanpää 2018), in order to achieve at least energy neutral treatment, this needs to be compensated by biogas production. Based on the BSR results achieved with energy key figure collection in the IWAMA project by Technical University of Berlin (Rettig et al. 2018) the median energy consumption in the region is 37 kWh PE⁻¹_{COD,120} in a year. With a good CHP around 1.5 – 2 kWh of electrical energy should be possible to produce from a m³ of biogas (CH₄ around 60%), which means in median values **around 50 to 70 L of biogas production per PE_{COD,120} per day should cover a WWTP’s total (electrical) energy demand.** Please bear in mind this

number could be significantly different based on your WWTPs energy demand and biogas energy conversion, as it describes Baltic Sea regional medians.

Possible limiting factors resulting in lower biogas production per $PE_{COD,120}$ are high sludge age (see Figure H on page 30), diluted influent wastewater with low BOD_5 and SS concentrations, too low primary sludge generation or under-dimensioning in digester volumes (cells “K91” and “M91” in the “Input” sheet, also described on pages 11 and 12). Possible boosting factors seen in the region are high amounts of external sludge loading to digesters (from smaller WWTPs in the area) and efficient co-digestion (loading of biodegradables).

The regional median value based on the key figure collection was about $25.4 \text{ L PE}^{-1}_{COD,120} \text{ d}^{-1}$, with $19 \text{ L PE}^{-1}_{COD,120} \text{ d}^{-1}$ as the 25th percentile and $32 \text{ L PE}^{-1}_{COD,120} \text{ d}^{-1}$ as the 75th percentile. These numbers refer to total biogas production, not methane (CH_4) production. Based on anaerobic digestion specific parameters the average methane content in the biogas should be around 55 to 65%.

- **Figure N – biogas production per WWTP PE (by COD load) without external substrates.** Based on the results from 18 WWTPs. The value shown on the figure is calculated based on WWTP $PE_{COD,120}$ value (more information on page 5) and reported daily biogas production. This figure does not take into account differences in the operation of anaerobic digestion (for example HRT, sequential digestion, intermittent hydrolysis).

The results for your WWTP can only be seen on the figure if cells “K17” (“WWTP capacity by COD”) and “K106” (“Biogas production”) in the “Input” sheet are filled. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the figure.

As Figures M to O refer to similar data, for extra information and explanations about the figure, please refer to the description provided under Figure M.

The regional median value based on the key figure collection was about $20.6 \text{ L PE}^{-1}_{COD,120} \text{ d}^{-1}$, with $18.4 \text{ L PE}^{-1}_{COD,120} \text{ d}^{-1}$ as the 25th percentile and $27 \text{ L PE}^{-1}_{COD,120} \text{ d}^{-1}$ as the 75th percentile. These numbers refer to total biogas production, not methane (CH_4) production. Based on anaerobic digestion specific parameters the average methane content in the biogas should be around 55 to 65%.

- **Figure O – biogas production per WWTP PE (by COD load) with external substrates.** Based on the results from 9 WWTPs. The value shown on the figure is calculated based on WWTP $PE_{COD,120}$ value (more information on page 5) and reported daily biogas production. This figure does not take into account differences in the operation of anaerobic digestion (for example HRT, sequential digestion, intermittent hydrolysis).

The results for your WWTP can only be seen on the figure if cells “K17” (“WWTP capacity by COD”) and “K106” (“Biogas production”) in the “Input” sheet are filled. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the figure.

As Figures M to O refer to similar data, for extra information and explanations about the figure, please refer to the description provided under Figure M.

The regional median value based on the key figure collection was about $32 \text{ L PE}^{-1}_{COD,120} \text{ d}^{-1}$, with $25 \text{ L PE}^{-1}_{COD,120} \text{ d}^{-1}$ as the 25th percentile and $58 \text{ L PE}^{-1}_{COD,120} \text{ d}^{-1}$ as the 75th percentile. As the array included in this figure is small, these numbers are rounded. Compared to results of WWTPs without external substrates, the produced biogas volumes are almost twofold. These numbers refer to total biogas production, not methane (CH_4) production. Based on anaerobic digestion specific parameters the average methane content in the biogas should be around 55 to 65%.

Subsection 4 – Biogas utilisation and energy production

This subsection consists of three figures about energy production from biogas. All of the figures are cumulative frequency graphs based on the key figure collection. This subsection is only open and figures shown if “Yes” is marked in cell “K84” (“Is digestion of the sludge applied in the WWTP”) in the “Input” sheet.

The three figures in this section refer to electricity and heat generation from biogas as separate types of energy and total energy production, which is a sum of electricity and heat production. While heat can be produced from multiple sources, electricity production can only be shown if a CHP is used in the WWTP.

This subsection has the following figures:

- Figure P – electricity production per m³ biogas.** Based on the results from 22 WWTPs. The value shown on the figure is calculated based on reported biogas use in CHP and reported electricity production. The background values do not take into account the specific content of methane in biogas, which in the background data differed from 54 to 67%.

The results for your WWTP can only be seen on the figure if “Yes” is selected in cell “K131” (“Is biogas used as a fuel in CHP”), and cells “K132” (“Average amount of biogas converted daily”) and “K133” (“Electricity production from CHP”) in the “Input” sheet are filled. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the figure.

In order to reach energy neutral or positive wastewater treatment, the electrical efficiency of CHP is of great importance. Research has shown that the electrical efficiency of a traditional Internal Combustion Engine (ICE) or Micro Gas Turbine (MGT) depends greatly on the CHP size, with 25-35% efficiency with small engines with the size up to 100 kWe and up to 38-45% with CHP bigger than 500 kWe (Nathalie Bachmann 2015). When taking into account a m³ of biogas with around 60% methane has a total of 6 kWh of energy in it, the WWTP should be able to produce from 1.5 to 2.7 kWh of electrical energy from a cubic meter of biogas, depending on the technology, size and age of the used CHP. In recent years Solid Oxide Fuel Cells (SOFC) have also risen in popularity as the generators are with high efficiency (up to 50-60%) with no bigger differences related to the size of the CHP (although needing more thorough biogas cleaning) (Gandiglio et al. 2017).

The regional median value based on the key figure collection was about 1.59 kWh/m³, with 0.94 kWh/m³ as the 25th percentile and 2.12 kWh/m³ as the 75th percentile.

- Figure Q – heat production per m³ biogas.** Based on the results from 17 WWTPs. The value shown on the figure is calculated based on both the reported biogas use and heat production in CHP and in separate heat production. The background values do not take into account the specific content of methane in biogas, which in the background data differed from 54 to 67%.

The results for your WWTP can only be seen on the figure if “Yes” is selected in either cell “K131” (“Is biogas used as a fuel in CHP?”) or “K136” (“Is biogas used as a fuel for heat production?”), and cells “K132” (“Average amount of biogas converted daily”) and “K134” (“Heat production from CHP”) or cells “K138” (“Average amount of biogas burned daily”) and “K139” (“Heat production from biogas burning”) in the “Input” sheet are filled. If both CHP and separate heat production are used, the amounts are added to each other. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the figure.

As previously mentioned, the a m³ of biogas with 60% of methane has a total energy content of 6 kWh. In CHP the heat generation depends on the electrical efficiency of the engine, with heat generated mainly as a co-product. Accounting to some minor losses (often considered close to 10-15%), around 2 to 3 kWh m⁻³ of usable heat is produced. As the CHP improvements have been focused on electrical efficiency, the amounts of heat produced with newer CHPs is often considerably lower (Gandiglio et al. 2017). When using

the biogas directly for heating the losses are smaller and close to 6 kWh of heat energy can be produced from m^3 of biogas.

The regional median value based on the key figure collection was about 2.5 kWh/ m^3 , with 1.8 kWh/ m^3 as the 25th percentile and 2.9 kWh/ m^3 as the 75th percentile.

- **Figure R – total energy production per m^3 biogas.** Based on the results from 20 WWTPs. The value shown on the figure is calculated based on both the reported biogas use, energy and heat production in CHP and in separate heat production. The background values do not take into account the specific content of methane in biogas, which in the background data differed from 54 to 67%.

The results for your WWTP can only be seen on the figure if “Yes” is selected in either cell “K131” (“Is biogas used as a fuel in CHP?”) or “K136” (“Is biogas used as a fuel for heat production?”), and cells “K132” (“Average amount of biogas converted daily”), “K133” (“Electricity production from CHP”) and “K134” (“Heat production from CHP”) or cells “K138” (“Average amount of biogas burned daily”) and “K139” (“Heat production from biogas burning”) in the “Input” sheet are filled. If both CHP and separate heat production are used, the amounts are added to each other. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the figure.

Once again, a m^3 of biogas with methane content of 60% has energy potential of around 6 kWh. Due to some losses in electricity transfer, the total amount of energy produced with CHPs is usually around 4.5 to 5.5 kWh m^{-3} . With direct conversion to heat energy, close to 6 kWh m^{-3} can be achievable. In the background information for this figure, not all reporting WWTP had values for both electrical and heat energy production, with larger number of WWTPs only measuring electricity production from CHPs. Therefore, some lower values don’t account for heat production as the values are not known.

The regional median value based on the key figure collection was about 4.34 kWh/ m^3 , with 2.47 kWh/ m^3 as the 25th percentile and 5.11 kWh/ m^3 as the 75th percentile.

Subsection 5 – Treated sludge quality and heavy metal concentrations

This subsection consists of eight figures about heavy metal (HM) concentrations in the treated sludge. Most of the figures are cumulative frequency graphs based on the key figure collection, while the first graph is a column chart comparing reported heavy metal concentrations to recommended limits.

Although in the recent decades a lot of research has been done on different possibly dangerous components in the treated wastewater sludge (hormones, pharmaceuticals, pesticides and many more), the main parameters still used in the legislation as quality criteria are heavy metal concentrations. The main reason for that is still the relative cost of more complex analysis organic components, while heavy metal analysis is affordable and widely performed any many laboratories. Therefore, this subsection is heavy metal concentrations, both in comparison with newer recommendations for direct use and regional data collected with the key figure collection.

Traditionally heavy metal concentrations are provided as mg per kilogram solids, the HELCOM suggestion (HELCOM Land-based Pollution Group 2014), which has been adapted into national legislation in some countries in the Baltic Sea region, also introduced an alternative unit (mg per kilogram of phosphorus in the sludge). Both of the alternatives are shown on Figure S in comparison to one another, while Figures T to Z use the conventional mg per kg total/dry solids as the prevailing unit.

Based on the choices made in the “Input” sheet of the SSMA tool, the reported heavy metal concentrations after the final treatment stage are used in all of the figures in this subsection. What is considered the final treatment stage in the SSMA tool can be checked in the “Laboratory data” sheet as the bottommost row is used for this comparison. If

heavy metal concentrations are not reported on that row, all of the figures in this subsection only show background information.

This subsection has the following figures:

- **Figure S – treated sludge HM concentrations compared to new HELCOM recommendations** (HELCOM Land-based Pollution Group 2014). This figure is not based on the background data collected during the key figure collection, but suggestions made by HELCOM for new heavy metal limit values in the sludge for direct use in agriculture Figure 8. These values were not included in the official recommendation, while have still been taken as basis for changes in the national legislations around the Baltic Sea region.

The most commonly analysed heavy metal limit values (first seven on Figure 8) are compared to the heavy metal concentrations reported in the “Laboratory data” sheet. As the raw limit numbers for heavy metals differ greatly, the results are given as percentages (specific limit value as 100% and reported heavy metal concentrations by the WWTP compared to that). An example of the figure and explanation on how to read it is given as Figure 9.

*Concentration of unwanted substances in sludge for use in agriculture
(one of the two limits should be used mg/kg DS or mg/kg P)*

Parameter	Concentration (mg/ kg DS)	Concentration (mg/kg P)
Cd	1	40
Cu	900	21 400
Ni	50	1 400
Pb	100	1 600
Zn	2 500	80 000
Hg	1	40
Cr	300	2 100
Ag	5	180
As	18	-
Tl	1.5	-
U	50 mg Uran/ kg P2O5	-
B(a)P (Benzo(a)pyren)	1	-
PCB (Polychlorinated Biphenyls)	0.1	2

Figure 8 - New limit values for heavy metal concentrations for sludge used directly in agriculture as suggested by HELCOM (HELCOM Land-based Pollution Group 2014). Both values for mg/kg DS and mg/kg P are viewed in the context of the SSMA tool. The value for Zn was accidentally incorrect in the published file and has been corrected with red. Only the first seven values indicated in this table have been used in comparison in the SSMA tool as these are the most common heavy metals analysed in the Baltic Sea region.

If the figure is missing information, please check that both heavy metal and phosphorus concentrations after last sludge treatment step are reported in the “Laboratory data” sheet. If any information is changed in the either the “Input” or “Laboratory data” sheet, please press “Process data and create audit results” button again to update the figure.

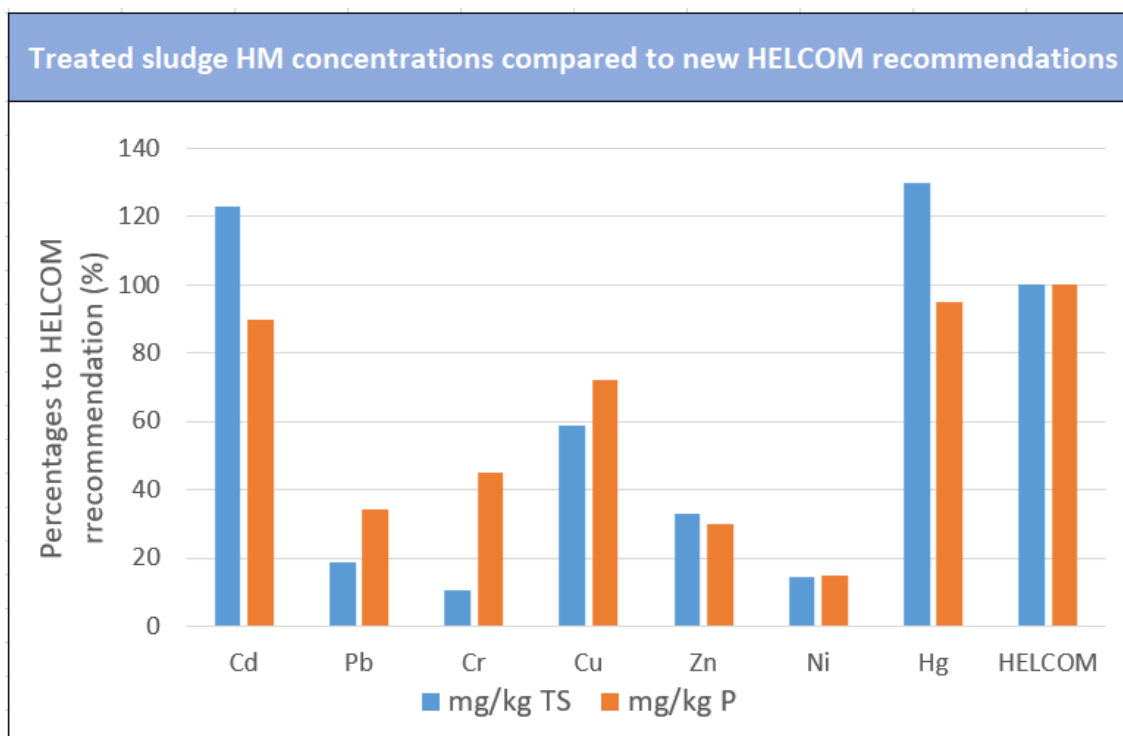


Figure 9 – Example of the treated sludge heavy metal concentrations comparison to new suggested limits by HELCOM (HELCOM Land-based Pollution Group 2014). Heavy metal data from last reported treatment stage is used in the comparison, suggested limits are shown on Figure 8. As the difference between limit values is very large (1 as lowest, 80 000 as highest), the limit values are transferred to percentages. Each column the reported heavy metal concentration in comparison to the suggested limits, blue column describes heavy metal limits per kilogram of solids while orange column describes heavy metal limits per kilogram of phosphorus in the sludge. For example on the figure above WWTP reported the Cd concentration as $1.23 \text{ mg kg}^{-1} \text{ TS}$ and $35.96 \text{ mg kg}^{-1} \text{ P}$ (calculated from P_{tot} of $34.2 \text{ g kg}^{-1} \text{ TS}$). As suggested limit value for Cd is either $1 \text{ mg kg}^{-1} \text{ TS}$ or $40 \text{ mg kg}^{-1} \text{ P}$, the WWTP reported values are shown as 123% compared to $\text{mg kg}^{-1} \text{ TS}$ and 89.9% compared to $\text{mg kg}^{-1} \text{ P}$. Therefore, when using total solids as comparison, the WWTP reported value is over the limit, while using phosphorus as comparison the WWTP reported value is just under the limit by a small margin.

- Figure T – Cd concentration.** Based on the results from 50 WWTPs. The background data shows all results gathered from the Baltic Sea region, with no differentiation on the specific sludge treatment technologies used. As the limits in the current EU treated wastewater sludge use for agriculture (marked as a green vertical line) differ greatly from the newer HELCOM suggestions (marked as a red vertical line), both can be seen on the figure.

In most cases high heavy metal concentrations (exceeding the limit values) are caused by industrial inflow accepted in the WWTP. As pollution from those sources can be unexpected (caused by emergencies or irregular discharge), this pollution can be difficult to detect. WWTPs not accepting industrial wastewater should not have problems with meeting the limit values, in other cases the possible pollution source can be a facility (research agency or etc), the urban environment (with combined stormwater system the city streets, cars, roofs, etc) or caused by natural background (thermal groundwater, abandoned old pollution sources, specific ground layers). Heavy metal concentrations in sludge are practically impossible to reduce with affordable means, some success has been seen with phytoremediation, while it's more efficient for very contaminated sludge rather than for minor problems meeting the limit values.

The regional median value based on the key figure collection was about $1 \text{ mg kg}^{-1} \text{ TS}$, with $0.6 \text{ mg kg}^{-1} \text{ TS}$ as the 25th percentile and $1.78 \text{ mg kg}^{-1} \text{ TS}$ as the 75th percentile. Different from all the other heavy metal concentrations, about half of the background WWTPs fail to achieve the new proposed HELCOM limit value, while 2 WWTPs in the array even struggled with the EU limit of $20 \text{ mg kg}^{-1} \text{ TS}$.

- **Figure U – Pb concentration.** Based on the results from 50 WWTPs. The background data shows all results gathered from the Baltic Sea region, with no differentiation on the specific sludge treatment technologies used. As the limits in the current EU treated wastewater sludge use for agriculture (marked as a green vertical line) differ greatly from the newer HELCOM suggestions (marked as a red vertical line), both can be seen on the figure.

More specific thoughts and explanations on heavy metal pollution are given under Figure T.

The regional median value based on the key figure collection was about 19 mg kg⁻¹ TS, with 12 mg kg⁻¹ TS as the 25th percentile and 27.7 mg kg⁻¹ TS as the 75th percentile.

- **Figure V – Cr concentration.** Based on the results from 49 WWTPs. The background data shows all results gathered from the Baltic Sea region, with no differentiation on the specific sludge treatment technologies used. As the limits in the current EU treated wastewater sludge use for agriculture (marked as a green vertical line) differ greatly from the newer HELCOM suggestions (marked as a red vertical line), both can be seen on the figure.

More specific thoughts and explanations on heavy metal pollution are given under Figure T.

The regional median value based on the key figure collection was about 31 mg kg⁻¹ TS, with 17 mg kg⁻¹ TS as the 25th percentile and 51 mg kg⁻¹ TS as the 75th percentile.

- **Figure W – Cu concentration.** Based on the results from 50 WWTPs. The background data shows all results gathered from the Baltic Sea region, with no differentiation on the specific sludge treatment technologies used. As the limits in the current EU treated wastewater sludge use for agriculture (marked as a green vertical line) differ greatly from the newer HELCOM suggestions (marked as a red vertical line), both can be seen on the figure.

More specific thoughts and explanations on heavy metal pollution are given under Figure T.

The regional median value based on the key figure collection was about 231 mg kg⁻¹ TS, with 150 mg kg⁻¹ TS as the 25th percentile and 359 mg kg⁻¹ TS as the 75th percentile.

- **Figure X – Zn concentration.** Based on the results from 50 WWTPs. The background data shows all results gathered from the Baltic Sea region, with no differentiation on the specific sludge treatment technologies used. As the limits in the current EU treated wastewater sludge use for agriculture (marked as a green vertical line) differ greatly from the newer HELCOM suggestions (marked as a red vertical line), both can be seen on the figure.

More specific thoughts and explanations on heavy metal pollution are given under Figure T.

The regional median value based on the key figure collection was about 549 mg kg⁻¹ TS, with 470 mg kg⁻¹ TS as the 25th percentile and 865 mg kg⁻¹ TS as the 75th percentile.

- **Figure Y – Ni concentration.** Based on the results from 50 WWTPs. The background data shows all results gathered from the Baltic Sea region, with no differentiation on the specific sludge treatment technologies used. As the limits in the current EU treated wastewater sludge use for agriculture (marked as a green vertical line) differ greatly from the newer HELCOM suggestions (marked as a red vertical line), both can be seen on the figure.

More specific thoughts and explanations on heavy metal pollution are given under Figure T.

The regional median value based on the key figure collection was about 19.3 mg kg⁻¹ TS, with 15.3 mg kg⁻¹ TS as the 25th percentile and 27.3 mg kg⁻¹ TS as the 75th percentile.

- **Figure Z – Hg concentration.** Based on the results from 50 WWTPs. The background data shows all results gathered from the Baltic Sea region, with no differentiation on the specific sludge treatment technologies used. As the limits in the current EU treated wastewater sludge use for agriculture (marked as a green vertical line) differ greatly from the newer HELCOM suggestions (marked as a red vertical line), both can be seen on the figure.

More specific thoughts and explanations on heavy metal pollution are given under Figure T.

The regional median value based on the key figure collection was about 0.48 mg kg⁻¹ TS, with 0.34 mg kg⁻¹ TS as the 25th percentile and 0.88 mg kg⁻¹ TS as the 75th percentile.

2.4 Section 4 – Audit results summary on sheet “Summary”

General rules

After the button “Process data and create audit results” has been pressed in the “Input” sheet, summary of the SSMA tool results can be found at the “Summary” sheet. Two different types of results are given on this sheet, the first are numerical results based on the median values of the Baltic Sea region; the second overall remarks on the treated sludge quality, potential problems and uses.

The first results are based on the key figures collection collected from 66 WWTPs in the Baltic Sea region during the IWAMA project. Benchmarks created from the key figure data have been published as a separate document, which can be found on the IWAMA webpage (“Key Figure Data for Sludge Benchmark”) (Raudkivi et al. 2018). These results have been used to calculate the “Placement”, which shows the location of respective result/indication in relation to the other WWTPs in BSR, this numbers are taken from respective cumulative frequency graphs explained in the guidelines document previously. Positive points in the column “Difference” appear when achieved value is better than the median of the region and vice versa. An example on how the summary tab should be read is shown on Figure 10.

For each subsection an “Overall” row is added which shows an arithmetic average of the results in the current subsection. In the end of the evaluations (“row 43”) an overall result of the basic sludge treatment parameters is given, calculated based on the “Overall” rows of the previous subsections. The “Basic wastewater characteristics” subsection is not included in this calculation as the influent concentrations can be evaluated but should not be taken directly into account when viewing the sludge treatment efficiency of the WWTP.

Basic wastewater characteristics				
Parameter	Value	Placement [%]	Difference [%]	Description
N/BOD ₅ ratio	0.164	19.64	30.36	With high N/BOD ₅ ratio dosing of extra organic carbon in the biological treatment becomes necessary as BOD ₅ in influent might not be enough to ensure sufficient N-removal. For WWTPs with primary clarification and higher N/BOD ₅ ratio, taking out too much primary sludge might prohibit biological N-removal even further or create extra need for external organic carbon dosing. The ratio for biological treatment without external dosing depends on various factors, but circa 0.25 is often counted as the maximum.
P/BOD ₅ ratio	0.021	15.00	35.00	The maximal possible ratio for biological phosphorus removal is often considered to be 0.01, with higher ratios chemical phosphorus removal is necessary. The higher the ratio the more dosing is needed.

Figure 10 – Example of the “Summary” sheet and numerical results subsection of the SSMA tool. The leftmost column “Parameter” shows which specific parameter was evaluated in this row; next column “Value” shows the achieved numerical value. “Placement” column shows the position of the result in relation to the values of other WWTPs in the BSR and “Difference” the achieved points from that. The points in “Difference” are calculated based on the difference from the median values of the specific parameter collected in the IWAMA project within the key figure collection. If lower values for the parameter are considered better, points are given for each % of placement under median values (in this example for N/BOD₅ ratio 50% (median) – 19.64% (WWTP placement within the frequency graph) = 30.36% (difference from median)). The “Description” column has some information on what the parameter shows with simple explanations given. Each subsection in the “Summary” tab also ends with “Overall” row, which shows the arithmetic average of the differences in the subsection (usually based on 2-4 parameters).

The second results (“Treated sludge quality and use”) beginning from row 48 indicate the quality and potential uses of the treated sludge. Different important parameters are shown in this section as well, while the results are given

as text. In this subsection the sludge stabilisation, hygienisation, heavy metal concentrations, nutrient concentrations and nutrient recovery potential is evaluated with recommended use indicated on the “Overall” row. As incinerated and non-incinerated sludge needs to be evaluated differently, separate subsections are given for the sludges. An example of the results in this subsection have been shown on Figure 11.

Treated sludge quality and use		
Non-incinerated sludge		
Parameter	Value	Description
Sludge stabilisation	Stabilisation achieved	Sludge is in most cases considered stabilised if during sludge treatment the organic content in the sludge is degraded sufficiently. Sludge is not considered stabilised if only the water content of sludge is lessened without any other treatment. Some treatment processes (humification) might take time to achieve stability, in those cases stability is appraised in the current tool through the ratio of volatile solids to total solids (stable sludge VS/TS < 0.6).
Hygienisation	Hygienisation achieved	The sludge treatment processes in the WWTP should guarantee hygienisation thanks to treatment at higher temperatures.
Heavy metal concentrations	Cd, Hg concentrations by mg/kg TS over HELCOM recommendations for agricultural use	Comparison values for heavy metal concentrations are taken from the draft of HELCOM Recommendation On Sewage Sludge Handling (Code 6-3), which proposed new and more strict limits of heavy metal concentrations for directly used sludge. These new values were unfortunately not included in the final version of the recommendation, but have since then been included in multiple local legal documents. The draft recommendation included two different options for limits, either compared to sludge total solids or phosphorus concentration.

Figure 11 – Example of the “Treated sludge quality and use” subsection of the “Summary” sheet. This example shows some results for “Non-incinerated sludge”, as incinerated sludge has a separate subsection with partially different results. The leftmost column “Parameter” shows which specific parameter was evaluated in this row; next column “Value” shows the achieved non-numerical value. The “Description” column has some information on what the parameter shows with simple explanations given. The subsection ends with the “Overall” row, which evaluates if the treated sludge could be used directly for agriculture based on the reported results alone (might require additional tests for hygienisation). The values and results in this subsection are estimations based on the reported data and used technologies, the real results may differ as some parameters, seasonal differences and possible situations unique to each WWTP could not be taken into account in the SSMA concept and tool.

The “Summary” sheet therefore shows the comparison of achieved results (based on reported information) both to other WWTPs in the Baltic Sea region and overall regional legislation, and therefore shouldn’t be considered as absolute as no comparison on how “good” the results are is given in the “Summary” sheet. Once again, please remember that we issue no guarantee on the correctness and completeness of the information and results in this tool. In case of interesting information or discoveries made using the SSMA concept or tool, we recommend consulting an outside expert before making any decisions with potentially financial implication.

As previously, not all results might be applicable and therefore filled for the reported WWTP – if the WWTP doesn’t use specific technology the results cannot be shown. Most of the rows not applicable to the specific WWTP should be hidden and not taken into account for the result calculations. If any rows are empty or not relevant rows are shown, please check the reported data in the “Input” sheet. Specific explanations are also given for each of the evaluated parameters with explanations based on which reported cells the result is given. If anything is changed in the “Input” or “Laboratory data” sheets, please press “Process data and create audit results” button again to update the results. If any problems persist, please use the contact information provided in the “Disclaimer” sheet and let us know.

As this sheet in the SSMA tool already has a description and explanation of the each of the results, in-depth background information in the guidelines document directly mirrors the “Description” column in the tool itself. Extra information can be found under the respective discussion in the “Figures and results” section.

Subsection 1 – Basic wastewater characteristics

Three different parameters concerning the influent wastewater characteristics are evaluated in this subsection. The “Overall” row (row 13) is calculated based on the arithmetic average of the three parameters (if data is missing on some of them, they are excluded from calculation). As stated previously, this “Overall” row is not taken into account when the overall efficiency of basic sludge treatment is calculated in row 43. Although influent parameters and concentrations can greatly influence the sludge treatment efficiency of the WWTP, these parameters are not under the direct control of the WWTP and therefore shouldn’t be taken directly into account. At the same time, while looking at the overall evaluations please compare them to the evaluations in this subsection – the negative overall in this subsection can influence sludge treatment results negatively as well. Specific instructions on how to read the results in this subsection can be seen on Figure 10.

Following parameters are evaluated in this subsection:

- Row 10 – N/BOD₅ ratio.** As discussed previously in the “Figures and results” section of the guidelines document, nitrogen concentrations in the influent can be very important, especially compared to the BOD₅ concentrations. The evaluation on this row is based on the data gathered with the key figure collection, the cumulative frequency graph, which can’t be seen in the SSMA tool, is included in the guidelines document as Figure 12. This evaluation uses reported values from cells “E11” and “G11” in the “Laboratory data” sheet, the ratio is calculated by dividing the total nitrogen concentration with the BOD₅ concentration. If one of those values is missing, this row will be empty.

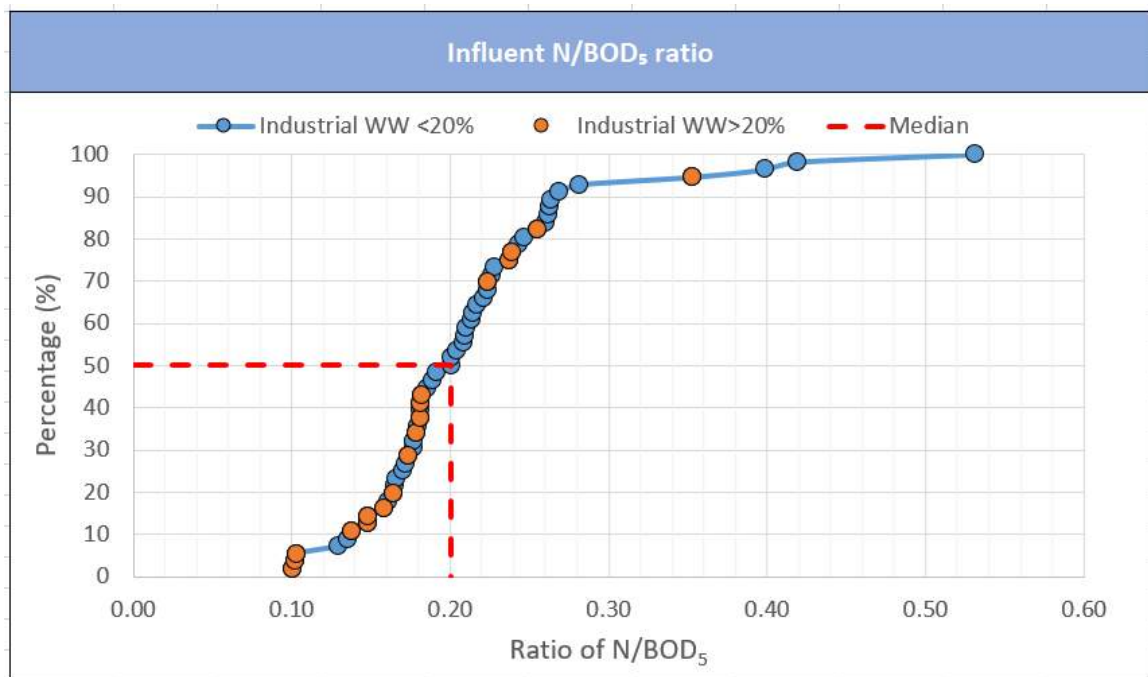


Figure 12 – The cumulative frequency graph of influent N/BOD₅ ratio, based on data collected from 56 WWTPs in the Baltic Sea region. The regional median value based on the key figure collection was about 0.2, with 0.186 as the 25th percentile and 0.238 as the 75th percentile. For biological nitrogen treatment without external organic carbon dosing, 0.25 is usually considered the maximal ratio.

With high N/BOD₅ ratio dosing of extra organic carbon in the biological treatment becomes necessary as BOD₅ in influent might not be enough to ensure sufficient N-removal. For WWTPs with primary clarification and higher N/BOD₅ ratio, taking out too much primary sludge might prohibit biological N-removal even further or create extra need for external organic carbon dosing. The ratio for biological

treatment without external dosing depends on various factors, but circa 0.25 is often counted as the maximum.

Positive difference for this parameter is considered as lower from the 50% median value shown on Figure 12.

- Row 11 – P/BOD₅ ratio.** Similar to nitrogen, the effect of high phosphorus concentration in the influent (as discussed previously in the “Figures and results” section of the guidelines document) is highly connected to BOD₅ concentration. The evaluation on this row is based on the data gathered with the key figure collection, the cumulative frequency graph, which can’t be seen in the SSMA tool, is included in the guidelines document as Figure 13. This evaluation uses reported values from cells “E11” and “I11” in the “Laboratory data” sheet, the ratio is calculated by dividing the total phosphorus concentration with the BOD₅ concentration. If one of those values is missing, this row will be empty.

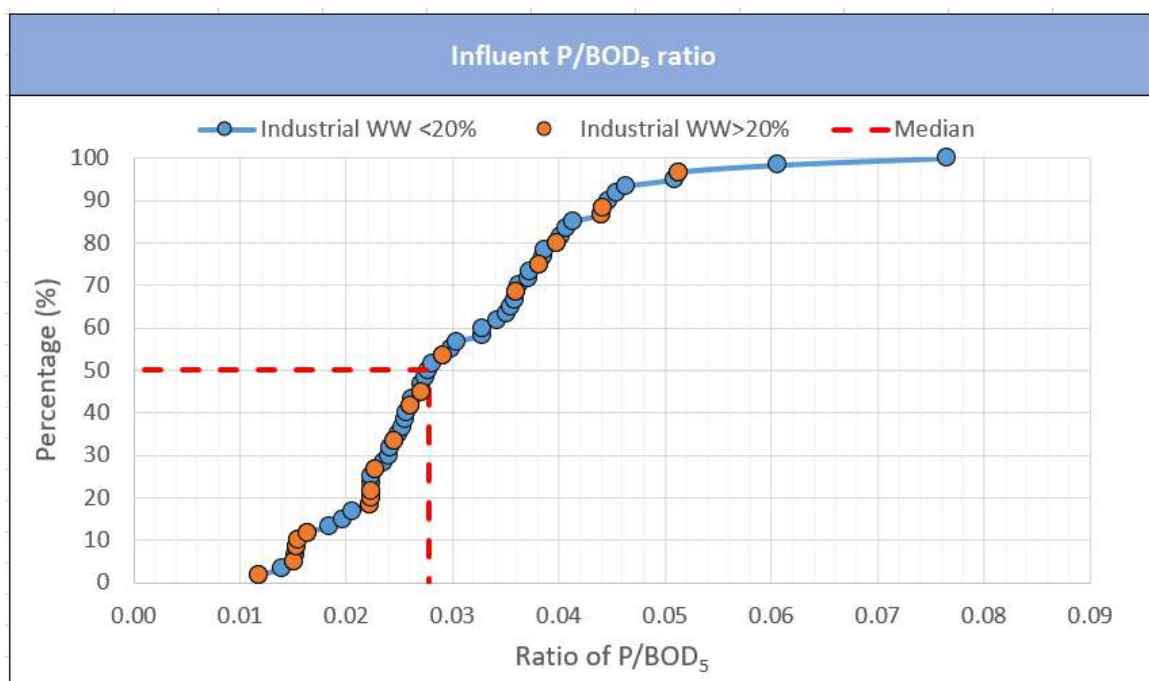


Figure 13 - The cumulative frequency graph of influent P/BOD₅ ratio, based on data collected from 60 WWTPs in the Baltic Sea region. The regional median value based on the key figure collection was about 0.028, with 0.022 as the 25th percentile and 0.038 as the 75th percentile. For fully biological phosphorus removal without chemical precipitation, 0.01 is usually considered the maximal ratio.

The maximal possible ratio for biological phosphorus removal is often considered to be 0.01, with higher ratios chemical phosphorus removal is necessary. The higher the ratio the more dosing is needed. Chemical phosphorus precipitation is the source of inert inorganic sludge production, which can significantly decrease the biogas production per loaded kg TS as the organic biodegradable carbon fraction in the sludge can be 20-30% lower. High precipitation can also negatively influence thickening and dewatering (significant difference when precipitation uses aluminium salts) (Derco 2016).

Positive difference for this parameter is considered as lower from the 50% median value shown on Figure 13.

- Row 12 – SS concentration [mg/L].** The SS concentrations and the cumulative frequency graph have been discussed in depth in the “Figures and results” section under Figure E on page 29. This evaluation uses reported value from cell “K11” in the “Laboratory data” sheet, if the value is missing, this row will be empty.
- Elevated levels of SS concentration are related to the increased surplus sludge production. High suspended solids concentration shows also higher potential gain of primary sludge from the primary clarification. As

primary sludge is with higher organic content, it also means higher biogas yield from anaerobic digestion. At the same time, in order to avoid organic carbon dosing in the biological treatment, WWTPs with high SS concentrations and high N/BOD₅ ratio might have to keep to retention time in the primary clarification lower in order to bring more influent organics to the biological treatment.

Positive difference for this parameter is considered as higher from the 50% median value shown on Figure E (“Influent SS concentration”) on “Figures and results” sheet.

- **Row 13 – overall.** Arithmetic average of the differences calculated for N/BOD₅ ratio, P/BOD₅ ratio and SS concentration. Overall difference based on wastewater characteristics show how much your WWTPs influent might affect the cost of treatment and other statistics compared to the average WWTP in the Baltic Sea region. As actual costs and other parameters are influenced by many other factors besides influent concentrations, this value does not affect all other values directly and linearly but gives an overall estimation on how much your influent might influence other results. Negative overall difference means the need to use chemical dosing of either organic substrate or coagulant is higher than average, which means extra costs for the WWTP. Please use this value as comparison with row 43, as the value calculated for this row is not taken into account for the overall basic sludge treatment efficiency calculation.

Subsection 2 – Thickening and dewatering

Two different parameters are evaluated in this subsection, one for thickening efficiency and one for dewatering efficiency. The “Overall” row (row 24) is calculated based on the arithmetic average of the two parameters (if data is missing on some of them, they are excluded from calculation). Both of these parameters and evaluations have been previously described under the “Figures and results” section in this guidelines tool.

Following parameters are evaluated in this subsection:

- **Row 22 – achieved TS with thickening [%].** The thickening efficiency and the cumulative frequency graph have been discussed in depth in the “Figures and results” section under Figure I on page 31. This evaluation uses reported solids content value from either cell “K68” (“Solids content in thickened mixed sludge”) or “K77” (“Solids content in the thickened secondary sludge”) in the “Input” sheet, depending on which type of thickening process is reported. If the corresponding value is missing, this row will be empty.

As more efficient thickening means lower total sludge amount, achieving higher thickening efficiency is very beneficial both for WWTPs with a digester (higher possible organics load) and other treatments (smaller sludge mass). Very high thickening efficiency is especially beneficial for WWTPs who transport their thickened sludge to other facilities for digestion or to a landfill.

Positive difference for this parameter is considered as higher from the 50% median value shown on Figure I (“TS achieved during thickening compared to used technologies”) on “Figures and results” sheet.

- **Row 23 – achieved TS with dewatering [%].** The dewatering efficiency and the cumulative frequency graph have been discussed in depth in the “Figures and results” section under Figure K on page 32. This row is only shown if dewatering is reported (“Yes” in cell “K112” (“Is dewatering used as a separate process”) in the “Input” sheet”). As previously mentioned, the dewatering greatly depends on the sludge quality, therefore with digested sludge higher TS content values can be reached. Therefore, this evaluation checks if sludge is digested or not before dewatering and uses different background information based on that (as shown on Figure K).

This evaluation uses reported value from cell “K120” (“Solids content in dewatered sludge”) in the “Input” sheet. If the value is missing, this row will be empty. Also, in order to differentiate between digested and undigested sludge, use of digestion is checked in cell “K84” (“Is digestion of the sludge applied in the WWTP?”) in the “Input” sheet. If the cell is empty (no selection made), this row will also be empty.

Similar to the thickening efficiency, higher dewatering efficiency also means a lower total sludge amount (especially by mass), which can be beneficial for further treatments (composting, drying and etc). Dewatering efficiency is considered good around 22-24% TS, very high efficiency might create problems with specific further treatment equipment (dryers). As the maximal dewaterability depends on the specific sludge, WWTPs having problems with their dewatering efficiency might consider a maximal dewaterability test, which shows the achievable values for the specific sludge.

Positive difference for this parameter is considered as higher from the 50% median value shown on Figure K ("Effect of digestion on achieved TS with dewatering") on "Figures and results" sheet.

- **Row 24 – overall.** Arithmetic average of the differences calculated for achieved TS with thickening and dewatering. Overall difference shows how the thickening and dewatering in the reported WWTP differs from average WWTP in the Baltic Sea region. If dewatering is not used in the WWTP, the "Overall" row shows the same difference value as for thickening. If one or both of the rows is empty (missing data), the data can't be used in the "Overall" calculation.

Result of TS content is significant in order to achieve cost-efficient sludge treatment and reasonable costs for transportation. Maximal efficiency of thickening and dewatering is crucial for WWTPs where further sludge treatment is not applied and sludge is transported to external company. Maximal dewaterability test is a tool which could give significant information about the value of achievable TS content.

Subsection 3 – Sludge age and anaerobic digestion

Three different parameters are evaluated in this subsection, one for sludge age and two for biogas production during anaerobic digestion. Sludge age is included in this subsection, because it can influence biogas production during anaerobic treatment. This is also discussed at length in the "Figures and results" section of the guidelines document, under Figure F and Figure H. As previously shown, biogas production also greatly depends on acceptance of extra biodegradable matter, therefore different evaluations are provided for those subcategories (row 31 for WWTP not accepting external substrates and row 32 for WWTP accepting external substrates). The alternative row not applicable for the WWTP is hidden from view. If the WWTP doesn't use digestion at all, only the sludge age evaluation on row 29 is seen in this subsection.

The "Overall" row (row 33) is calculated based on the arithmetic average of the three parameters (if data is missing on some of them, they are excluded from the calculation). All of these parameters and evaluations have been previously described under the "Figures and results" section in this guidelines tool.

Following parameters are evaluated in this subsection:

- **Row 29 – sludge age [d].** Calculated sludge age, according to Equation 1 has been used for this evaluation. The calculated sludge age effects and the cumulative frequency graph have been discussed in depth in the "Figures and results" section under Figure F and Figure H on pages 29 and 30. This evaluation uses the calculated value from cell "K35" ("Calculated simple t_{ss} in the biological treatment") in the "Input" sheet. If any information is changed in the "Input" sheet, please press "Process data and create audit results" button again to update the evaluation.

The optimal sludge age in the biological treatment depends a lot on other WWTP parameters, such as average wastewater temperatures and sludge treatment technologies. For a WWTP with anaerobic digestion, the optimal sludge age is considered to be 15 days, as with higher sludge age organic content in the secondary sludge starts to degrade resulting in lower potential biogas yield. For a WWTP without digestion, this organic degradation results in more stabilized sludge, therefore higher sludge age might be beneficial for other sludge treatment processes.

For WWTPs with anaerobic digestion, the positive difference for this parameter is considered as lower from the 50% median value shown on Figure F ("Simple sludge age calculated") on "Figures and results" sheet. For WWTPs without anaerobic digestion, the positive difference for this parameter is considered as higher from the 50% median value shown on Figure F ("Simple sludge age calculated") on "Figures and results" sheet.

- **Row 30 – biogas production by TS loaded [$\text{m}^3/(\text{kg TS}\cdot\text{d})$].** The biogas production per TS loaded and the cumulative frequency graph have been discussed in depth in the "Figures and results" section under Figure L on page 33. The row is only shown if anaerobic digestion is used in the WWTP ("Yes" marked in cell "K84" in the "Input" sheet). This evaluation uses data from cells "K101" ("Average daily amount of inflow to the digester") and "K106" ("Biogas production") in the "Input" sheet. If any information is changed in the "Input" sheet, please press "Process data and create audit results" button again to update the evaluation.

Optimal biogas production for municipal WWTP is $0.3\text{--}0.4 \text{ m}^3/(\text{kg TS}\cdot\text{d})$. Low biogas production is usually caused by lower content of biodegradable organic compounds added to digester. Biogas production could be substantially increased by co-digesting if suitable co-substance is available in the region and full capacity of digester(s) is not used (over-dimensioned digester). Recommended co-substances are organic residues from food industry which have high calorific values and do not reduce the quality of treated sludge. If necessary infrastructure and full-loaded methane digester are available in the WWTP and the region has high potential of biodegradable organic waste, investing to additional digester may be considered to increase the energy dependence of the plant.

Positive difference for this parameter is considered as higher from the 50% median value shown on Figure L ("Biogas production per TS loaded to digester") on "Figures and results" sheet.

- **Row 31 – biogas production by WWTP PE [$\text{L}/(\text{PE}\cdot\text{d})$] without external substrates.** The biogas production per WWTP $\text{PE}_{\text{COD},120}$ has been discussed in depth in the "Figures and results" section under Figures M to O on pages 33 to 34. The row is only shown if anaerobic digestion is used in the WWTP ("Yes" marked in cell "K84" in the "Input" sheet). This evaluation checks if biodegradables are added to the digestion, this specific row is only shown when "No" is marked in cell "K94" ("Are any biodegradables (OFMSW, grease from grease trap, etc) added to digestion") in the "Input" sheet. The evaluation also uses the calculated value from cell "K17" ("WWTP capacity by COD ($\text{PE}_{\text{COD},120}$)") and cell "K106" ("Biogas production") in the "Input" sheet. If any information is changed in the "Input" sheet, please press "Process data and create audit results" button again to update the evaluation.

Higher values are mainly achieved by accepting sludge from other WWTPs, external biodegradable materials or having very high industrial inflow. Smaller WWTPs have higher possibilities to increase this value by accepting external substrates.

Positive difference for this parameter is considered as higher from the 50% median value shown on Figure N ("Biogas production per WWTP PE (by COD load) without external substrates") on "Figures and results" sheet.

- **Row 32 – biogas production by WWTP PE [$\text{L}/(\text{PE}\cdot\text{d})$] with external substrates.** The biogas production per WWTP $\text{PE}_{\text{COD},120}$ has been discussed in depth in the "Figures and results" section under Figures M to O on pages 33 to 34. The row is only shown if anaerobic digestion is used in the WWTP ("Yes" marked in cell "K84" in the "Input" sheet). This evaluation checks if biodegradables are added to the digestion, this specific row is only shown when "Yes" is marked in cell "K94" ("Are any biodegradables (OFMSW, grease from grease trap, etc) added to digestion") in the "Input" sheet. The evaluation also uses the calculated value from cell "K17" ("WWTP capacity by COD ($\text{PE}_{\text{COD},120}$)") and cell "K106" ("Biogas production") in the "Input" sheet. If any information is changed in the "Input" sheet, please press "Process data and create audit results" button again to update the evaluation.

Higher values are mainly achieved by accepting sludge from other WWTPs, external biodegradable materials or having very high industrial inflow. Smaller WWTPs have higher possibilities to increase this value by accepting external substrates.

Positive difference for this parameter is considered as higher from the 50% median value shown on Figure O ("Biogas production per WWTP PE (by COD load) with external substrates") on "Figures and results" sheet.

- **Row 33 – overall.** Arithmetic average of the differences calculated for sludge age and biogas production. Overall difference shows how the anaerobic digestion and biogas production in the reported WWTP differs from average WWTP in the Baltic Sea region. If anaerobic digestion is not used in the WWTP, the "Overall" row shows the same difference value as for sludge age. If one or more of the rows are empty (missing data), the data can't be used in the "Overall" calculation.

Sludge age and anaerobic digestion parameters show the potential of increasing biogas production compared to other WWTPs in the region. The aim of WWTP is treating wastewater, however, sustainability of the plant could be increased by reducing the requirement of external energy source. In order to achieve energy neutral or energy positive WWT, which is up-and-coming trend in the region, biogas production has to be optimized to the maximal capacity.

Subsection 4 – Energy production from biogas

Three different parameters are evaluated in this subsection, all of them concerning energy production from biogas utilisation. Both electrical energy and heat are viewed separately with the third evaluation to total energy production. This is also discussed at length in the "Figures and results" section of the guidelines document, under Figures P to R. The evaluation in this section is only shown if anaerobic digestion is used in the WWTP ("Yes" marked in cell "K84" in the "Input" sheet). As the type of energy produced depends greatly on the biogas utilisation way, some rows are not shown when biogas is sold outside, used only for heating or etc.

The "Overall" row (row 41) is calculated based on the arithmetic average of the three parameters (if data is missing on some of them, they are excluded from the calculation). All of these parameters and evaluations have been previously described under the "Figures and results" section in this guidelines tool.

By theoretical calculations a cubic meter of biogas (around 60% of methane) has the total energy potential of 6 kWh. Practically close to 6 kWh is obtainable, if only heat is produced from the biogas as electricity generator has considerable losses. With a good CHP, around 2 kWh of electricity and 2.5 kWh of heat is considered optimal (a total of 4.5 kWh), 1.5 kWh is usually lost due to energy transfer. Real results may vary a bit due to different concentrations of methane in biogas, applied technologies and measuring inconsistencies.

Following parameters are evaluated in this subsection:

- **Row 38 – Electricity production from biogas [kWh/m³].** The electricity production and the cumulative frequency graph have been discussed in depth in the "Figures and results" section under Figure P on page 35. This evaluation is only shown if the use of a CHP is reported in cell "K131" ("Is biogas used as fuel in CHP?") in the "Input" sheet and cells "K132" ("Average amount of biogas converted daily") and "K133" ("Electricity production from CHP") are filled. If any information is changed in the "Input" sheet, please press "Process data and create audit results" button again to update the evaluation.

Positive difference for this parameter is considered as higher from the 50% median value shown on Figure P ("Electricity production per m³ biogas") on "Figures and results" sheet.

- **Row 39 – Heat production from biogas [kWh/m³].** The heat production and the cumulative frequency graph have been discussed in depth in the "Figures and results" section under Figure Q on page 35. This evaluation is only shown if either the use of a CHP is reported in cell "K131" ("Is biogas used as fuel in CHP?") or the use of heating with biogas is reported in cell "K136" ("Is biogas used as fuel for heat production") in the "Input" sheet and respectively cells "K132" ("Average amount of biogas converted daily") and "K134" ("Heat production from CHP") or cells "K138" ("Average amount of biogas burned daily") and "K139" ("Heat

production from biogas burning”) are filled. If both biogas utilisation ways are used, the results will be summed up. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the evaluation.

Positive difference for this parameter is considered as higher from the 50% median value shown on Figure Q (“Heat production per m³ biogas”) on “Figures and results” sheet.

- **Row 40 – Total energy production from biogas [kWh/m³].** The total energy production and the cumulative frequency graph have been discussed in depth in the “Figures and results” section under Figure R on page 36. This evaluation is only shown if either the use of a CHP is reported in cell “K131” (“Is biogas used as fuel in CHP?”) or the use of heating with biogas is reported in cell “K136” (“Is biogas used as fuel for heat production”) in the “Input” sheet and respectively cells “K132” (“Average amount of biogas converted daily”), “K133” (“Electricity production from CHP”) and cell “K134” (“Heat production from CHP”) or cells “K138” (“Average amount of biogas burned daily”) and “K139” (“Heat production from biogas burning”) are filled. If both biogas utilisation ways are used, the results will be summed up. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the evaluation.

Positive difference for this parameter is considered as higher from the 50% median value shown on Figure R (“Total energy production per m³ biogas”) on “Figures and results” sheet.

- **Row 41 – overall.** Arithmetic average of the differences calculated for electricity, heat and total energy production. Overall difference shows how the production of energy in the reported WWTP differs from average WWTP in the Baltic Sea region. If anaerobic digestion or biogas utilisation for energy is not used in the WWTP, this whole section is hidden. If one or more of the rows are empty (missing data), the data can’t be used in the “Overall” calculation.

Energy production values depend on what type of energy is produced, efficiency of technology (e.g. CHP) as well as operation. For more information previous sections of the guidelines document should be checked as indicated for each of the specific evaluations.

Subsection 5 – Overall efficiency of basic sludge treatment

The overall efficiency of basic sludge treatment, taking into account the thickening and dewatering, sludge age, biogas production and energy production is calculated in row 43. This result is the arithmetic average of the previous overall rows (excluding basic wastewater characteristics on row 13. If some rows and section were hidden, this calculation excludes them, calculating arithmetic average from only the subsections relevant to the reported WWTP.

Although a single numerical value is given for the overall efficiency of sludge treatment, this only shows on average how the reported WWTP compares to other WWTPs in the Baltic Sea region. A positive overall value shows that the WWTP has achieved better results on average for the evaluated parameters than the neighbouring WWTPs, negative overall value shows that results on average were worse than the median result of the region. As all evaluated parameters are considered equally, this value can be greatly influenced if even one of them differs from median values greatly – therefore this final value should only be taken as a light indicator and not as the most important value given by the SSMA tool.

Please bear in mind that the overall efficiency of basic sludge treatment depends on many factors, not all of them evaluated in this section. Characteristics of sludge should be tested before purchasing new treatment equipment and chemicals as specific sludge in the WWTP might differ from other sludge in the region. Although sludge treatment is one of the most expensive parts of wastewater treatment, costs could be substantially optimised by smart operation – the aim of the SSMA tool is to give you a simple indication in which processes the optimisation potential could be

hidden. Before making any decisions based on the findings of the SSMA tool with potential financial implications, please conduct a more thorough investigation or contact external experts for more specific and relevant results.

Subsection 6 – Treated sludge quality and use – incinerated sludge

This subsection gives a light evaluation for 6 different parameters connected to the final quality and usability of the sludge. The parameters evaluated are common throughout the region although the specific limit values and restriction can be different depending on the country. The main evaluated parameters are sludge stabilisation, hygienisation and heavy metal concentrations, with extra emphasis on potential nitrogen and phosphorus recovery from sludge. This specific subsection deals with incinerated sludge, where for example sludge stabilisation and hygienisation is guaranteed. These parameters will still be shown and shortly described, while they do not change based on the operation of the incineration plant. As the main use for incineration ash in the current legislative environment is for phosphorus fertiliser production, the most important parameter calculated in this subsection is the total P-recovery potential from the ash.

This subsection is opened if “Yes” is marked in cell “K149” (“Are processes for sludge treatment applied?”) and “Drying and incineration” is marked in cell “K151” (“Which method is used for sludge treatment after digestion?”) in the “Input” sheet. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the evaluation.

Following parameters are evaluated in this subsection:

- **Row 52 – sludge stabilisation.** As mentioned previously sludge stabilisation is guaranteed in incineration, as all organic content in the sludge is destroyed. The result for this parameter does not change based on any of the information reported in the SSMA tool.
- **Row 53 – hygienisation.** Similar to stabilisation, as incineration takes place at very high temperatures and all organic content is destroyed, the hygienisation of sludge is guaranteed for incineration ash. The result for this parameter does not change based on any of the information reported in the SSMA tool.
- **Row 54 – heavy metal concentrations.** Heavy metal concentrations in the sludge are very important for direct use. As incineration ash is not used directly, the concentrations are not considered important. Specific technologies for phosphorus recovery from incineration ash might be influenced by specific heavy metals, but that is greatly dependant on the technology used. Heavy metal concentrations are still evaluated in the “Treated sludge quality and heavy metal concentration” subsection in the “Figures and results” sheet, if more specific information is necessary. The result for this parameter does not change based on any of the information reported in the SSMA tool.
- **Row 55 – N-recovery potential.** Incineration process evaporates almost all nitrogen from the sludge, making nitrogen recovery from ash impossible. Therefore, the N-recovery potential is always marked as “None” and does not change based on any of the information reported in the SSMA tool.
- **Row 56 – P-recovery potential [t P/a].** As mentioned previously the phosphorus recovery potential is the most important parameter for WWTPs with incineration at the moment, as more and more emphasis and requirements are set on incinerated ash to be used for fertiliser production. This evaluation includes a calculation based on your reported data, using the values from cells “C27” and “H27” in the “Laboratory data” sheet (more information can be found on page 24). If these values are not available or empty, the phosphorus recovery potential value will be empty.

For this evaluation approximate annual recoverable phosphorus amount is calculated and shown, showing total phosphorus content in the ash based on reported data. This does not account the yield of different phosphorus recovery processes, actually recoverable phosphorus amounts can differ significantly. In

reference, the estimated annual phosphorus input needed in the while EU is around 3.85 million tons (Tóth et al. 2014), while the gross phosphorus balance on agricultural land in the EU is around 1.2 kg P per hectare per year (period 2013-2015) (Eurostat 2018).

- **Rows 57 and 58 – actual P-recovery.** Both of these rows evaluate whether phosphorus recovery is actually used in the WWTP, with row 57 showing the result of “Phosphorus recovered from ash” and row 58 “Phosphorus not recovered from ash”. The row 57 is shown if “Yes” is marked in cell “K178” (“Is P recovered from ash?”) in the “Input” sheet, while row 58 is shown if “No” is marked instead.

As mentioned previously phosphorus recovery from incineration ashes is a novel topic that has become more and more vital, with even first changes in legislation around the corner. If phosphorus recovery is not used yet in the WWTP (usually an outside company receives the incineration ashes for P-recovery), it is highly recommended to look into possible options for the near future. There is a very high probability P-recovery from incineration ash will become mandatory in the coming years so researching possible options before that should be high in the priority list.

Subsection 7 – Treated sludge quality and use – non-incinerated sludge

This subsection gives a light evaluation for 6 different parameters connected to the final quality and usability of the sludge. The parameters evaluated are common throughout the region although the specific limit values and restriction can be different depending on the country. The main evaluated parameters are sludge stabilisation, hygienisation and heavy metal concentrations, with extra emphasis on potential nitrogen and phosphorus recovery from sludge. This specific subsection deals with non-incinerated sludge, where for example sludge stabilisation and hygienisation are not guaranteed. The most important parameters calculated in this subsection are the total nitrogen and phosphorus recovery potentials from the treated sludge.

This subsection is opened in all other cases besides if “Yes” is marked in cell “K149” (“Are processes for sludge treatment applied?”) and “Drying and incineration” is marked in cell “K151” (“Which method is used for sludge treatment after digestion?”) in the “Input” sheet. In the latter case, subsection 6 is opened instead. If any information is changed in the “Input” sheet, please press “Process data and create audit results” button again to update the evaluation.

Following parameters are evaluated in this subsection:

- **Rows 63 and 64 – sludge stabilisation.** Both of these rows evaluate whether treated sludge achieves stability, with row 63 showing the result of “Stabilisation achieved” and row 64 “Stabilisation not achieved”. The row 63 is shown if digestion is applied or any further treatment technologies are applied in the WWTP, while row 64 is shown if no treatment besides thickening and dewatering are applied.

Sludge is in most cases considered stabilised if during sludge treatment the organic content in the sludge is degraded sufficiently. Sludge is not considered stabilised if only the water content of sludge is lessened without any other treatment. Some treatment processes (humification) might take time to achieve stability, in stability should be achieved when VS/TS ration is under 0.6. In such cases, please conduct a separate stability evaluation, as stabilisation is marked “achieved” in the SSMA tool.

- **Rows 65 and 66 – hygienisation.** Both of these rows evaluate whether treated sludge achieves hygienisation, with row 65 showing the result of “Hygienisation achieved” and row 66 “Hygienisation not assured”. The row 63 is shown only if drying is used in the WWTP, while row 64 is shown if other treatment technologies or no treatment is applied. As separate hygienisation equipment is not reported in the SSMA tool, WWTPs using hygienisation should disregard the result given in this evaluation.

Most sludge treatment processes in the WWTP don't automatically guarantee hygienisation, therefore if separate hygienisation process is not applied we recommend testing the treated sludge for E.Coli and Helminths, which serve as microbial and parasitical contamination indicators.

- **Rows 67 and 68 – heavy metal concentrations.** Both of these rows evaluate whether there are problems with achieving previously shown limit values (Figure 8), with row 67 showing the result if some problems with achieving limit values are apparent based on reported values and row 68 “No problems with achieving heavy metal concentrations for agricultural use outlined in HELCOM recommendations” if all reported values are under the shown limits. Based on the choices made in the “Input” sheet of the SSMA tool, the reported heavy metal concentrations after the final treatment stage are used in this evaluation. What is considered the final treatment stage in the SSMA tool can be checked in the “Laboratory data” sheet as the bottommost row is used for this comparison. If heavy metal concentrations are not reported on that row, problems can't be identified and these evaluations should be disregarded.

Comparison values for heavy metal concentrations are taken from the draft of HELCOM Recommendation On Sewage Sludge Handling (Code 4-1) (HELCOM Land-based Pollution Group 2014), which proposed new and more strict limits of heavy metal concentrations for directly used sludge. These new values were unfortunately not included in the final version of the recommendation but have since then been included in multiple local legal documents. The draft recommendation included two different options for limits, either compared to sludge total solids or phosphorus concentration. Both options are considered and reported on row 67.

- **Row 69 – N-recovery potential.** Evaluates the potential of nitrogen recovery from the treated sludge. Uses the data from the final reported sludge treatment technology (final row open in the “Laboratory data” sheet). If the daily amount of sludge (column C) or the TN concentration (Column F) is missing, “Data not found” will be seen in the evaluation. In other cases the annual nitrogen amount in the treated sludge is calculated based on the reported values.

Although the main emphasis in nutrient recycling is on phosphorus, nitrogen is also considered an important nutrient for plant growth. Most sludge treatment process substantially degrades nitrogen in the process, while the treated sludge usually still has quite high nitrogen content suitable for fertilizers or direct applications in agriculture or greenery.

- **Row 70 – P-recovery potential.** Evaluates the potential of phosphorus recovery from the treated sludge. Uses the data from the final reported sludge treatment technology (final row open in the “Laboratory data” sheet). If the daily amount of sludge (column C) or the P_{tot} concentration (Column H) is missing, “Data not found” will be seen in the evaluation. In other cases the annual phosphorus amount in the treated sludge is calculated based on the reported values.

As phosphorus is considered the main limiting factor for plant growth, phosphorus fertilizers are very commonly used. Recycling phosphorus from waste streams, especially from treated sludge has been a very widely discussed topic for the last decade. Recycling phosphorus is a good example of the circular economy we are trying to move towards and therefore if possible, phosphorus from the treated sludge should be reused either directly (greenery, agriculture) or via chemical extraction. For this evaluation approximate annual recoverable phosphorus amount is calculated and shown, showing total phosphorus content in the sludge based on reported data. In reference, the estimated annual phosphorus input needed in the while EU is around 3.85 million tons (Tóth et al. 2014), while the gross phosphorus balance on agricultural land in the EU is around 1.2 kg P per hectare per year (period 2013-2015) (Eurostat 2018).

- **Rows 71 and 72 – actual nutrient recovery.** Both of these rows evaluate whether direct use of treated sludge and with that direct nutrient recovery is currently used in the WWTP. If either cell “K214” (“Final usage of sludge in greenery”), “K215” (“Final usage of sludge in recultivation”) or “K216” (“Final usage of sludge in agriculture”) in the “Input” sheet has reported data, row 71 is shown (“At least part of phosphorus and nitrogen recovered via direct use of sludge”), in other cases row 72 is open (“Phosphorus and nitrogen not recovered”). External treatment of sludge is not considered in this case, as it is difficult to appraise, what another company is doing with the sludge.

In the context of this audit tool, nutrients are considered recovered at least partially, if some of the treated sludge is used in agriculture, recultivation or greenery. If the sludge quality doesn't allow for a direct use, incineration and subsequent recovery of phosphorus from ashes is considered the most viable option. At the same time, incineration evaporates nitrogen from sludge, making nitrogen recovery impossible.

- **Rows 73 and 74 – overall.** Both of these rows evaluate whether treated sludge based on the information reported in the SSMA tool is considered safe for direct use in agriculture. Overall evaluation is given considering sludge stability, hygienisation and heavy metal concentrations, other parameters and local legal requirements might have to be considered before making the decision for direct use. The specific limit values for stability, hygienisation and heavy metal concentration used in this tool might also differ regionally, therefore this overall evaluation shouldn't be seen as permission or prohibition for direct use of treated sludge, but as an evaluation of the limited data provided.

Row 73 ("Treated sludge recommended for direct use in agriculture, recultivation or greenery") is only shown if all evaluate parameters were considered safe. In most cases, this row is not shown as the evaluation of hygienisation requires external data and should be tested. Row 74 ("Treated sludge not recommended for direct use in agriculture") is shown in most cases, if any of the reported parameters showed possible problems or safety couldn't be guaranteed based on the reported information. In many cases, external analyses can prove the sludge quality is good enough for direct use in agriculture. If different results have been achieved with laboratory analysis, disregard this evaluation.

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