Application of the preliminary ENERWATER methodology for energy audit of wastewater treatment plants in Italy

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INTRODUCTION

One of the higher costs of wastewater services is the energy consumption. The total electricity consumption in wastewater treatment plants (WWTPs) corresponds to about 1% of the total electricity consumption per year of a country (Cao et al., 2011). In Italy the electricity demand account for about 1% of total production of the country (Foladori, 2010). In Spain the electricity demand for domestic and industrial water cycle responds to 2-3% of total energy consumption (Fundación OPTI, 2012). In the United States, it has been estimated that roughly 4% of the electricity demand is employed in distribution/collection and potabilization/treatment of water and wastewater, by public and private stakeholders (Goldstein et al., 2002). The energy consumption in the wastewater cycle system accounts for about 1% in Sweden and 3% in UK of the overall energy consumption in the country (Bodík and Kubaská, 2013). Energy consumption represents a significant part of the operation cost of WWTPs but, with a correct design and a careful management model, there are important possibilities for its limitation (Panepinto et al., 2016). In order to compare WWTPs having different processes and scheme configuration, the most useful methodology is efficiency assessment using benchmarking procedures (Parena et al., 2002). Using benchmarking methodologies the best operational practices can be identified (Molinos-Senante et al., 2014). Performance Indicators have been proposed in WWTPs but not many details were given about energy consumption in the single stage of WWTPs (Gordon and McCann, 2015). On the other hand, the available audit methodologies are not well supporting the decisions of the water utilities in order to best target their actions to improve the energy efficiency. This support is particularly crucial when the decision should take into account dozens WWTPs, each one operating according to complex treatment stages. Traditionally, energy consumption of a WWTP has been simplistically reported using global KPIs such as kWh/m^3 (Mizuta and Shimada, 2010) or kWh/PE (Krampe, 2013; Balmer, 2000). In order to summarize all the information provided by the performance indicators in a single comprehensive ranking indicator, the use of weightings on the removal of the pollutants based on their impact were considered (Benedetti et al., 2008).). However, WWTPs are composed by several stages, each one with different function. Therefore the use of specific KPIs for each treatment stage is more appropriate (Longo et al., 2016). A standard methodology is required in order to carry out the energy audit in WWTPs (Tao et al., 2009). In order to cover the European normative lag, the Horizon2020 ENERWATER (H2020-EE-2014-3-MarketUptake) project (www.enerwater.eu) is being developed in order to validate and disseminate an innovative standard methodology for continuously assessing, labelling and improving the overall performance of WWTPs. For that purpose a collaboration framework in the water treatment sector including research groups, water utilities, city councils, water authorities and industry was implemented. ENERWATER will devote important efforts to ensure that the methods are widely adopted. Subsequent objectives are to impulse dialogue towards the creation of a specific European legislation following the example of recently approved EU Directive 2003/66/EC, to establish a way forward to achieve EU energy reductions objectives for 2020, ensuring effluent water quality, environmental protection and compliance with Water Framework Directive. In ENERWATER methodology, a review of WWTP energy-use performance was carried out and proposed on Deliverable D2.1. An innovative methodology was set up in the different stages of the WWTPs where different and comprehensive key performance indicators (KPIs) were considered and proposed on Deliverable D3.1. The energy audit methodology and tool was built and proposed on Deliverable D2.4 taking into account even recent relevant national guidelines and obligations such as the Italian Legislative Decree 102/2014. The energy audit was carried out in 50 WWTPs located in Italy, Spain and Germany. This paper presents results of the application of preliminary ENERWATER methodology (D3.2) to 15 relevant Italian WWTPs managed by the ENERWATER partner ETRA S.p.A, aiming at the final preliminary energy labelling. These results will be reviewed and refined in the course of the ENERWATER project thanks to the on-line metering and tools which will be the basis of the definitive ENERWATER methodology that will be even evaluated for European standardization.

MATERIAL AND METHODS

Benchmarking approach

The preliminary ENERWATER benchmark grouped the WWTPs according to homogeneous treatment potential (size, in population equivalent – PE) defined in Metcalf & Eddy (2006) classification: PE < 2 k; 2 k < PE < 10 k; 10 k < PE < 50; 50 k < PE < 100 k; PE > 100 k. The benchmark includes key performance parameters calculated in each stage of the 50 WWTPs of the ENERWATER consortium in Italy, Spain and Germany.

Treatment stage classification

Taking into account the different processes and treatment schemes applied in municipal WWTPs seven treatment stages were used to disaggregate the energy consumption data,:

Stage 1: *Preliminary treatment,* which includes raw wastewater pumping station, equipment involved in screening, grit removal, oil separation, flow equalization, storm water equalization and pumping

Stage 2: *Primary treatment,* which includes all equipment involved on primary sedimentation. Pumps for primary sludge extraction and dose of chemicals were considered in this stage.

Stage 3: *Secondary treatment,* which includes all the processes and the equipment required for biological wastewater treatment. Possible operation units included in this stage are trickling filters, conventional activated sludge, nutrient removal reactors and secondary sedimentation. Equipment such as blowers, mechanical aerators, internal and sludge recycle pumps, excess sludge pumps, mixers and chemicals dosage were also included in this stage.

Stage 4: *Tertiary and advanced treatment,* which includes a wide variety of processes and equipment: chemical (e.g.: chlorination or ozonation), physical (e.g.: sand filters, UV disinfection) and biological (e.g.: reed-beds, tertiary nitrification, post-denitrification) were included in this stage.

Stage 5: *Sludge treatment,* which includes thickening, dewatering, sludge stabilisation and thermal process (e.g: drying, gasification, pyrolysis and incineration).

Stage 6: *Return liquors treatment* can include processes for treatment of reject water that are usually focused on nitrogen and phosphorus removal.

Stage 7: *Odour treatment,* which includes recovering and treatment of extracted air from sludge processing technologies. Moreover general services are included in this study.

The following are considered general services: local and remote monitoring and control room, blowers' room, transformation cabin room and electrical generator.

Key Performance Indicator (KPIs)

Wastewater treatment plants can be composed by a very wide variety of processes designed for removal pollutants from wastewater that has been discharged to a central facility. Various methodologies have been described to estimate specific energy consumption in WWTPs. The limitations of existing methodologies are related with the need to compare similar wastewater pollutant loads at the influent, including relevant parameters such as the carbon to nitrogen ratios, and effluent concentrations. In order to obtain a comparable, real and universal form of energy data reporting, suitable KPIs within the WWTPs were proposed (Table 1).

Table 1. Key performance indicators

Stage treatment	KPIs
Stage 1	kWh/m^3
Stage 2	kWh/kg $TSS_{removed}$
Stage 3	kWh/kg $COD_{removed}$
	kWh/kg $NH4_{removed}$
	kWh/kg $TN_{removed}$
	kWh/kg $TP_{removed}$
Stage 4	kWh/kg $TSS_{removed}$
	kWh/kg $NH4_{removed}$
	kWh/kg $TN_{removed}$
	kWh/kg $TP_{removed}$
	kWh/$Log_{reduction}$
	kWh/$Estradiol_{removed}$
Stage 5	kWh/kg $TS_{processed}$
	$kWh_{produced}$/kg $VS_{removed}$
Stage 6	kWh/kg $TP_{removed}$
	kWh/kg $TN_{removed}$
Stage 7	kWh/kg $VOCs_{removed}$
	kWh/kg $VICs_{removed}$
	kWh/kg $VSCs_{removed}$

In this preliminary study, the KPIs were calculated considering influent characteristics and literature removal efficiency in each stage (Metcalf and Eddy, 2014).

Energy Audit Preliminary Methodology

As far as the energy audit preliminary methodology is concerned, ENERWATER has initially considered the application of Italian Decree 102/2014 which has recently been adopted to audit large WWTPs in Italy. The plant energy structure can be represented by an energy scheme in which each use of energy carriers is described. The energy consumptions are structured according to the following different levels (from A to D):

- Level A (LA) is characterized by the description of the general data of the WWTP, i.e.: Company, Country, Name of WWTP, City, Auditor, WWTP measured size [PE], flow-rate [m^3/y] and date of audit.
- Level B (LB) is the point of maximum synthesis of the energy structure for each energy carrier. The specific energy carrier is called Vj, where j varies from 1 to n, and n is the number of vectors corresponding to the indexes of the energy carrier (electricity j = 1, diesel fuel j = 2, natural gas j = 3, biogas j = 4).
- Level C (LC) is a first schematic mapping of the energy utilization and is characterized by a distribution of the energy carrier Vj in the following functional areas (Table 2):
  - Main activities – including the main aim (removal of contaminants from wastewater) of the plant;
  - General services - including the transformation of the energy carrier input in different possible energy sources (e.g. the electrical generator using diesel fuel (input carrier) to produce electrical energy (output carrier)).
  - Auxiliary services - (e.g: lighting, heating, air-conditioning, offices, canteen, etc.…).
- Level D (LD) identifies the details of structure for the different energy carriers used in each process/equipment of the WWTP.

Table 2. Energy audit Level C – Functional areas

LEVEL C – Functional areas		
MAIN ACTIVITIES	**GENERAL SERVICES**	**AUXILIARY SERVICES**
Treatment Stage 1	Electric transformer room	Offices
Treatment Stage 2	Remote monitoring/control room	Laboratories
Treatment Stage 3	Electric panels room	Dressing room
Treatment Stage 4	Compressor room	
Treatment Stage 5	Power generator	
Treatment Stage 6	Co-generator of Heat and Power (CHP)	
Treatment Stage 7		

Energy Audit Preliminary Tool

The tool was built in Microsoft Excel in order to be accessible to the widest range of operators and practitioners and includes the following steps:

1. General Information (Level A);
2. Energy Carrier (Level B);
3. Functional Areas (Level C);
4. Processes (Level D);
5. Energy model;
6. Key Performance Indicators;
7. Final Template;
8. Benchmarking;
9. Wastewater Treatment Energy Index;
10. Charts;

All the energy uses were characterized and a detailed inventory including more than 30 items per plant was compiled. The inventory reported the name of the equipment, the place in the WWTP according to the treatment stage, the power requirement in kW, the working hours and the use factor. Thanks to these information it was possible calculate the energy consumption of each equipment by Equation 1:

$$V_1 = \frac{P*t*U.F}{\eta}\ [kWh/year] \qquad \text{(Equation 1)}$$

Where: V_1 is the energy consumption when electric energy was used as energy carrier; P is the power of electrical motor in kilowatt (kW) , t is the working hours every year (h/year), U.F is the use factor (represents the ratio among the real power that the device delivers and the nominal power that the device could deliver); η is the efficiency and considers the energy losses for internal distribution and energy losses related to the conversion from medium voltage (MV) to low voltage (LV) (MV/LV transformation).

A bottleneck of such a preliminary calculation is related to the age and wearing out of the equipment that was not taken into consideration. On the other hand, the definitive ENERWATER methodology will be based on the continuous on-line metering of the real electric consumption. For electrical generators, V_2 (Diesel Fuel) was considered as energy carrier. In order to transform the kg of used diesel in kWh, the lower calorific value and the efficiency of the generators was taken into account. The energy production of CHP, using as energy carrier V_3 (natural gas) and/or V_4 (biogas) was known by the presence of metering devices.
As mentioned above, the calculation of the KPIs considers chemical-physical characteristics of the influent wastewater, while technical literature (Metcalf and Eddy, 2006) was considered to estimate the removal efficiency of the different treatment stages. The results of the KPIs were obtained through the mass balance in the processes present in each stage treatment.

Comparison among ENERWATER methodology and literature studies

Table 3 shows the comparison between the preliminary ENERWATER and other methodologies.

Table 3. Literature studies on energy audit in municipal WWTPs

Reference	Methodology	Stage treatment	Performance indicators	Main considerations
ENERWATER	Energy Audit and Benchmarking in 50 WWPTs in Germany, Spain and Italy. -Survey -Equipment inventory -Energy consumption calculation In this work 15 WWTPs in Italy	Figure 1 General services Auxiliary Services	Table 2	Benchmarking and evaluation of energy consumption in each treatment/process. Disaggregated energy consumption per each equipment. Performance indicators in function of the stage. Online energy audit tool. Metering devices will be installed. Sampling campaign will be carried out.
US EPA, 2010	Online energy tool. Survey, Equipment inventory, energy consumption calculation. Energy cosy	NO	kWh/m^3	Benchmarking and evaluation of energy consumption. Performance indicators, cost information and energy score. Energy and cost saving opportunities.
Tao and Chengwen (2009)	Data collection of 1856 WWTPs in China	NO	kWh/m^3 and kWh/COD	Only aggregated energy data were considered
Panepinto et al., 2016	Energy audit in 1 WWPT in Italy -Survey -Equipment inventory -Energy consumption calculation -Evaluation of thermal energy consumption	Water line Sludge line	kWh/m^3 kWh/TN kWh/COD, kWh/PE/y	Evaluation of energy consumption in each treatment/process. Energy saving and cost were considered. Overall performance indicators.
Foladori et al., 2010	Energy audit carried out in 5 WWTPs in Italy. -Survey, -Equipment inventory -Energy consumption calculation	hydraulic-based COD-based Sludge-based Buildings	kWh/m^3 kWh/COD kWh/PE/y	Evaluation of energy consumption in each treatment/process and identification of performance indicators. In function of the stage.
Yang et al., 2010	Data collection of 559 WWTPs in China	NO	kWh/m^3 kWh/(total pollutant removed) kWh/(Influent pump unit per volume treated) kWh/(air provided for aeration) kWh/(amount of sludge treated)	Evaluation of overall energy consumption. Identification of different performance indicators, energy performance index
Belloir et al., 2015	Data collection of 2 WWTPs in UK	NO	kWh/m^3	Considers overall energy consumption and energy saving opportunities.
Mizuta and Shimada (2010)	Data collection of 985 WWTPs in Japan	NO	kWh/m^3	Considers overall energy consumption
Bálmer (2010)	Data collection of 5 WWPTs in North Europe	NO	kWh/PE/y	Considers overall energy consumption and chemical consumption
Molinos-Senante et al., 2013	Data collection of 192 WWTPs in Valencia	NO	€/m^3,	non-radial DEA model constitutes a useful benchmarking methodology to identify cost-saving opportunities in WWTPs
Krampe (2013)	Data collection of 24 WWTPs in Australia	NO	kWh/PE/y	Evaluation of specific energy consumption in pump station, UV and disinfection.
Bodík and Kubaská (2013)	Data collection of 51 large WWTPs and 17 rural WWTPs in Slovakia	NO	kWh/m^3, kWh/COD,	Considers overall energy consumption, Energy production from biogas. Energy benchmark reported for plant size classification
Alidrisi 2014	Data collection of 8WWTPs in the Middle West	NO	kWh/BOD kWh/TSS	Considers overall energy consumption
Sala-Garrido et al., 2011	Data collection of 99 WWTPs in Catalonia	NO	Total Cost	Considers overall energy consumption in function of different technologies

Generally, almost all the energy audit and benchmarking approach are based on estimation of overall energy consumption of the WWTP and consider basic performance indicators. The US EPA methodology compares the actual energy consumption with the benchmark in order to obtain an energy score and comment on energy & cost saving. Basic information was reported about specific energy consumption per each process/equipment. Foladori et al. (2010) adopted a consistent approach considering different treatment stages and performance indicators. Panepinto et al. (2016) adopted a multi-step methodology for energy consumption estimation and proposed performance indicators anyway referred to whole WWTP. Yang et al. (2010) estimated the overall energy consumption and the proposed performance indicators were not linked to the different stage treatment. In this regard ENERWATER methodology shows an important innovation because the municipal WWTPs are divided in 7 treatment stages, each one considered for proper performance indicators. In this way the decision to best target the energy efficiency actions is supported. ENERWATER methodology considers aggregated and disaggregated energy data, while the related audit tool estimates energy consumption and calculates performance indicators.

Case studies

Fifteen Italian WWTPs managed by ETRA SpA were considered for the validation of the preliminary methodology as task of the ENERWATER project (Table 4). These WWTPs were audited and compared with the current ENERWATER benchmark. The preliminary audit was carried out to gather information on flow-scheme, process parameters and data regarding the electro-mechanic equipment and devices (i.e. power, power factor, operating time, etc..).

Table 4. Influent and effluent characteristics of the Italian WWTPs audited within ENERWATER (Average data over one year)

WWTPs	Size	Flow-rate	COD		TN		TP		TSS	
	[PE]	[m^3/d]	[mg/L]		[mg/L]		[mg/L]		[mg/L]	
			in	out	in	out	in	out	in	out
IT_01	20,000	4,086	202	18	17.6	4.4	3.2	0.3	118	5
IT_02	98,000	12,919	294	42	36.6	11.6	4.5	0.7	89	6
IT_03	50,000	10,796	259	26.8	36.2	7.9	4.5	0.9	143	9
IT_04	35,000	10,137	364	26	36	9	6	1	229	10
IT_05	20,000	2,981	388	28	33	10	6	1	176	10
IT_06	7,000	1,572	379	30	57	8.5	5.5	1.4	188	10
IT_07	61,500	9,460	419	27.9	51	11	5.6	0.6	139	10
IT_08	20,000	2,589	290	24	51	10.7	6.1	0.8	173	10
IT_09	12,800	1,815	413	28.2	74.6	7.4	9.2	0.8	157	10
IT_10	20,000	3,578	365	36	35	11.4	9.4	0.7	149	11
IT_11	22,000	3,572	558	25	69	10	7	0.88	217	10
IT_12	20,000	3,465	544	27	71.5	11.4	9.8	0.6	233	10
IT_13	100,000	13,886	137	25	23	7.9	2.7	0.6	49	5
IT_14	12,000	2,118	352	23	91	7.7	8	0.3	139	10
IT_15	48,000	14,596	368	20	41.5	6.6	5.2	0.47	143	9

Using the information collected during the pre-audit survey, the preliminary ENERWATER tool was able to estimate the energy consumption of each process and equipment, calculate the KPIs and compare them with the currently available ENERWATER benchmark.

RESULTS AND DISCUSSION

Energy audit

Gathered data from pre-audit were input to the ENERWATER tool which output the estimations shown in Table 5. Within the ENERWATER project, these estimation will be refined thanks to the real-time measurements by on-line devices currently under installation.

Table 5. Estimated energy consumptions [kWh/y]

WWTPs	IT_01	IT_02	IT_03	IT_04	IT_05	IT_06	IT_07	IT_08	IT_09	IT_10	IT_11	IT_12	IT_13	IT_14	IT_15
Size [PE]	20000	98000	50000	35000	20000	7000	61500	20000	12800	20000	22000	20000	100000	12000	48000
Flow rate [m^3/y]	1491363	4715384	3940656	3699816	1088207	573494	3452673	945139	662483	1305862	1303777	1264623	5068454	772982	5327675
Preliminary treatment								***STAGE1***							
Influent pumping	67279	90252	340634	169689	26109	35152	291810	99579	34080	99978	149053	206800	224185	63331	276876
Screening	13132	26958	86069	11949	22076	6542	5239	4832	2335	13587	7895	10941		6459	5157
Grit removal	304	8481	74391	82763	27499			25263				8842	22592		80870
Storm water Tank			14001	2255									14173		465
Equalizing Basin											42105				
Effluent pumping			69600	140921				78316		109251					
Primary treatment								***STAGE 2***							
Primary sedimentation		13775					6891								
Primary sludge pump		33747					7989								
Secondary treatment								***STAGE 3***							
Blower oxidation	429606	1383431	708986	729800	630361	243760	1060779	1001921		285853	358491	422841	1041616	231579	714079
Agitator denitrification	77556	202215	151713	213318	55146	22984	144739	55156		113158	45974	84211	201381	54461	315282
Recycling pump	3008	233449	72805	10873	1813	16842			15651		4611	74526	60632	28632	108510
Secondary sedimentation	20277	20676	20688	20605	13579	13503	20672	27474	13781	13792	27584	13792	20603	6887	10346
Return sludge pump	119197	110232	162467	129646	123555	30287	156212	73903	57162	134872	57171	26105	392422	137874	158257
Excess sludge pump		3381	11526	75137	6310	3158		2782	4371	3339		5564	13620	7158	11925
Mechanical aerator		138000								721				590832	
Secondary sludge pumping		79314								108274	65701				
Intermitted aeration									551260						
Tertiary treatment								***STAGE 4***							
Tertiary filtration	18270	27663	64632	73393											319875
UV disinfection			70030												203200
Post-Denitrification		196175													
Sludge Treatment								***STAGE 5***							
Thickener	3937	72118		22632	6894		13763							12632	
Sludge press	33297	112943	164007	278947	22854	42105	99095	43421		77895	56084	77895	124968	47368	231679
Anaerobic digester				37047											
Aerobic stabilization								177263		63158		81684			
Storage Sludge tank							96874								
Sludge Dehydratation		1424391													
								General Services							
Electric Transformer cabin	2766		5618	5618									1466		
Remote control room			9221										9464		
electric panel Room			6127	5072											
Compressor Room	5072		6127	6127									59		
CHP				3940937											
Electrical generator	232	1972	1503	1503	1183	1183	1380	1183	1183	1183		789	1624	789	1183
TOTAL > TOOL ESTIMATION	793933	4179173	2040145	2017295	937379	415516	1905443	1591093	679823	1025061	814669	1013990	2128805	1188002	2437704
TOTAL > REAL ENERGY BILLS	506198	4108024	4257952	2942565	1088427	389784	2630187	1362803	426772	1065466	811307	848786	1748028	627534	4257952
% ERROR	56.8%	1.7%	-52.1%	-31.4%	-13.9 %	6.6%	-27.6%	16.8%	59.3%	-3.8%	0.4%	19.5%	21.8%	89.3%	-42.7%

Generally stage 3 was most energy-consuming mainly due the aeration equipment (blowers and/or mechanical aerator). In other stages the following equipment were the most energy-consuming: stage 1 → influent pumping; stage 2 → primary sludge pumps; stage 4 → tertiary filtration; stage 5 → sludge dewatering. In order to validate the preliminary ENERWATER methodology and tools, the results of the energy audit were compared with the real overall energy consumption reported in the energy bills of the year 2015. The differences among the estimated energy demand and the real energy consumption (Table 5) were lower than the 30% for nine WWTPs, while for six WWTPs the errors were slightly higher. These errors demonstrate how the real-time measurements are needed for the better reliability of the methodology and related tool.
The possible causes for the observed errors can be the following: (a) the age and the wearing out of the equipment was not taken into account, (b) the power use of some electrical devices was not available, so it was estimated on the basis of literature data, (c) blowers or bigger pumps with frequency regulators can cause a big deviation from the actual consumption, (d) the possible unavailability of data of energy consumption of the general services and auxiliaries, (e) the possible overestimation of the ratio between used and nominal power 100%.

Comparison with the current ENERWATER benchmark

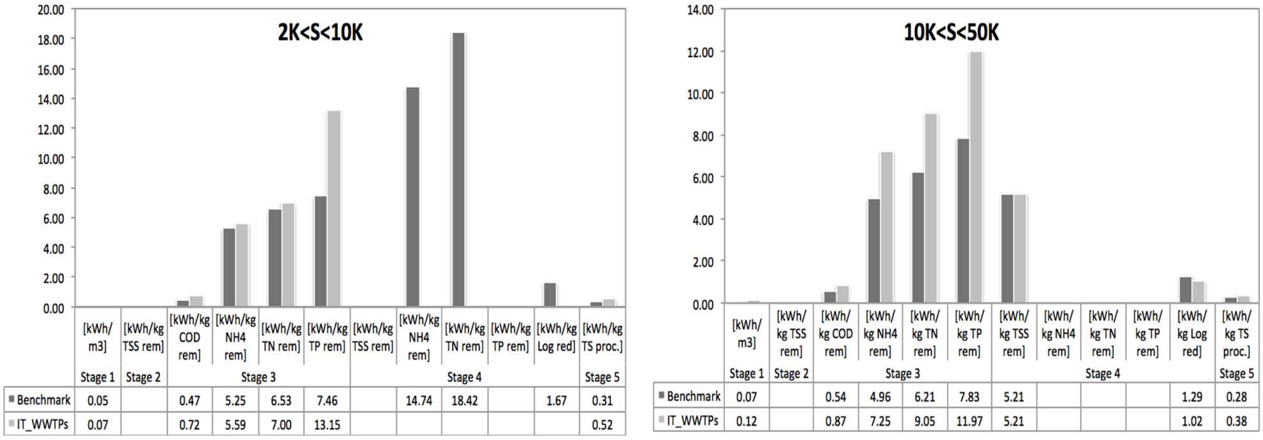
The preliminary energy audit was carried out in 50 WWTPs analysed in the ENERWATER project in order to develop the current ENERWATER benchmarking of KPIs. The use of the KPIs allowed a general evaluation of the energy consumptions in the different treatment stages of each WWTP. Starting from influent and effluent characteristics, the tool calculated the KPIs showed in Table 1 considering literature removal efficiency in each stage (Metcalf and Eddy, 2006). In order to compare the results of the energy audit, carried out on Italian WWTPs, with the current benchmark, the WWTP IT_06 was included in the size classification of 2K<S<10K. The WTTPs IT_01, IT_03, IT_04, IT_05, IT_08, IT_09, IT_10, IT_11, IT_12, IT_13, IT_14 and IT_15 were included in the size classification of 10K<S<50K. The size of WWTPs IT_02, IT_07 and IT_13 was included in the size classification of 50K<S<100K. Table 6, shows the calculated KPIs in the Italian WWTPs.

Table 6 Calculated key performance indicators for Italian WWTPs

		IT_01	IT_02	IT_03	IT_04	IT_05	IT_06	IT_07	IT_08	IT_09	IT_10	IT_11	IT_12	IT_13	IT_14	IT_15
	Size [PE]	20000	98000	50000	35000	20000	7000	61500	20000	12800	20000	22000	20000	100000	12000	48000
Stage 1	[kWh/m^3]	0.054	0.027	0.148	0.11	0.07	0.073	0.086	0.22	0.055	0.171	0.153	0.179	0.051	0.09	0.068
Stage 2	[kWh/kg $TSS_{removed}$]		0.188					0.05								
Stage 3	[kWh/kg $COD_{removed}$]	1.02	0.99	0.39	0.42	0.93	0.72	0.61	2.02	1.12	0.66	0.37	0.43	0.87	1.85	0.32
	[kWh/kg $NH4_{removed}$]	13.73	8.05	3.41	4.91	12.83	5.59	5.02	13.42	7.21	5.29	3.45	3.85	6.79	8.3	3.31
	[kWh/kg $TN_{removed}$]	17.2	10.1	4.2	6.1	16	7	6.3	16.8	9	6.6	4.3	4.8	8.5	10.4	4.1
	[kWh/kg $TP_{removed}$]	16.96	15.14	5.96	6.65	15.9	13.15	10.44	25.34	13.17	6.69	7.66	6.33	11.03	21.08	5.91
Stage 4	[kWh/kg $TSS_{removed}$]	2.72	8.79	3.79	2.2											12.12
	[kWh/kg $NH4_{removed}$]		6.91													
	[kWh/kg $TN_{removed}$]		8.64													
	[kWh/kg $TP_{removed}$]		11.79													
	[kWh/$Log_{reduction}$]	0.1	1.23	0.73	0.4											2.86
Stage 5	[kWh/kg $TS_{processed}$]	0.14	0.54	0.24	0.71	0.11	0.52	0.11	0.81	0.16	0.52	0.19	0.59	0.09	0.37	0.36

As reported below, in the current preliminary ENERWATER methodology the KPIs were calculated considering literature removal efficiency in each stage/process treatment. After the installation of ENERWATER real-time metering devices the real removal efficiency will be measured by samples analyses before and after each treatment stage. Figure 1 shows and compares the specific energy consumptions in different stages according to the treatment capacity (size) classification. This size classification 50K<S<100K was not reported because of the low statistic relevance in the ENERWATER audited WWTPs.

Figure 1. Comparison between Benchmark and Italian WWTPs in each stage, per size classification



Generally the comparison with the benchmark showed that the stage 3 could be more energy-efficient. On the other hand, Stage 1 and Stage 5 were in line with ENERWATER benchmark. However, although the potential of the tool is clear, many additional data are necessary to feed the benchmark especially for size 50K<S<100K.

CONCLUSIONS

The application of the preliminary ENERWATER methodology and tool to benchmark and audit the municipal WWTPs advanced the current state of the art and allowed: (1) the comparison among homogenous classes of plants grouped according to their treatment capacity; (2) the disaggregation of the key performance indicators within different treatment stages that support to target the energy efficiency actions in each WWTP.

Main bottleneck of the current preliminary methodology is the lack of real-time measurements and wastewater characterizations throughout the treatment stages. This gap will be filled by the ENERWATER project (www.enerwater.eu) which will allow the real-time energy audit and planning of the best targeted actions to improve energy efficiency.

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