ENERWATER

Simpozij z mednarodno udeležbo

VODNI DNEVI 2017

Application of the ENERWATER methodology for the analysis of energy efficiency: a case study

Coordinator: Almudena Hospido
Universidade de Santiago de Compostela
Stefano Longo

SLOVENSKO DRUŠTVO ZA ZAŠČITO VODA

ENERWATER objectives

This project develops, validates and disseminates a standard methodology for the evaluation and increase of energy efficiency in WWTPs

The methodology must be:

- **Standardized**: to allow sound comparisons between different plants and operators
- **Generic**: Adapted to different typologies of WWTPs
- **Open**: Anyone must be capable of using it and understand how the results are obtained.

The ENERWATER consortium

Budget 1 731 087 €

March 2015 – February 2018

University of Santiago de Compostela (ES)

University of Verona (IT)

University of Cranfield (UK)

Technical University of Cologne (DE)

Espina y Delfín (ES)

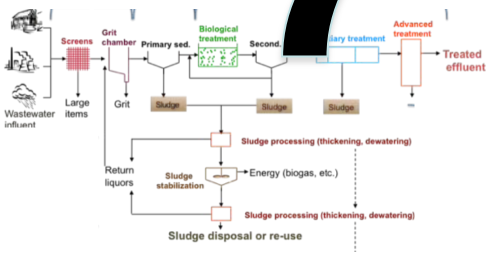
ETRA (IT)

Aggerverband (DE)

AENOR (ES)

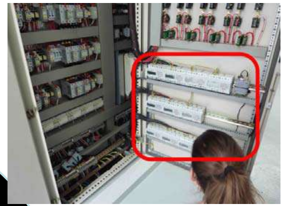
Wellness Smart Cities (ES)

ENERWATER methodology: Overview



WWTP

Online energy monitoring



DATA TREATMENT

Influent and effluent analysis

Communication
Water Treatment Energy Index - WTEI

Diagnosis
Which stages are less efficient?

DEFINE

MEASURE

ANALYSE

ENERWATER

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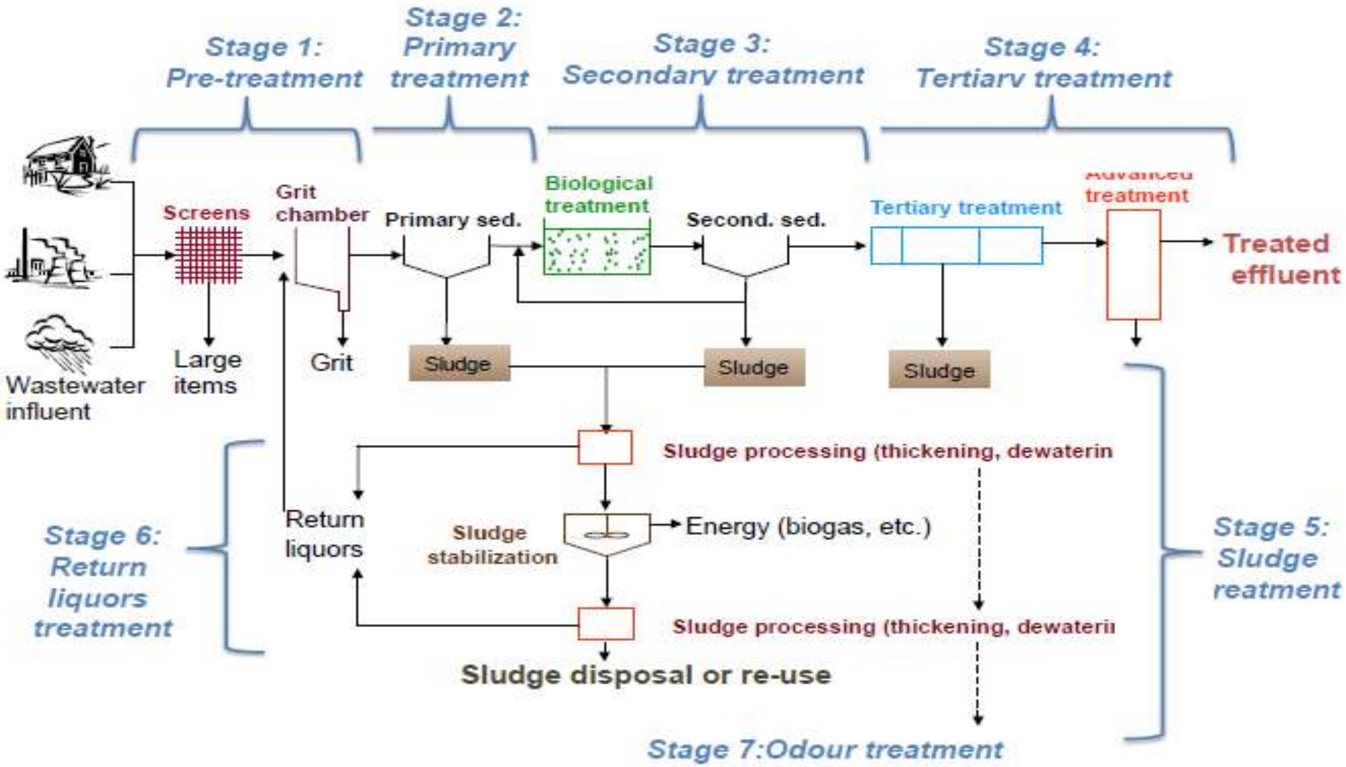
ENERWATER methodology: Overview

STAGE CLASSIFICATION

In order to disaggregate the energy consumption data, taking into account the different processes and treatment schemes applied in municipal WWTPs, 7 stage were used.



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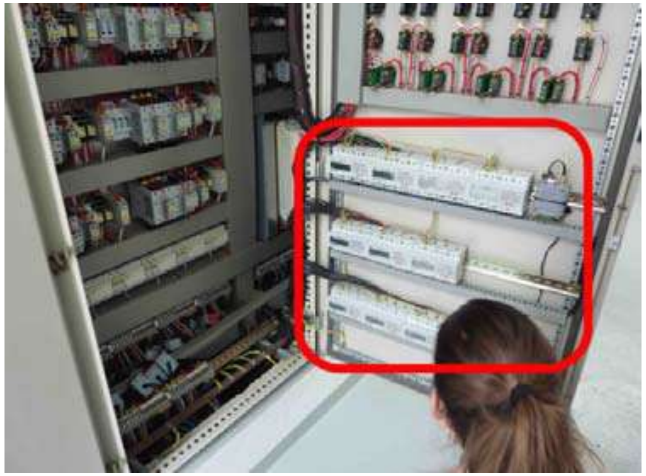
ENERWATER methodology: Overview

KEY PERFORMANCE INDICATORS (<u>KPIs</u>)

There is a clear need to establish suitable KPIs within the WWTP that allow a comparable, realistic and universal form of reporting the energy data.

STAGE CLASSIFICATION	KPIs
STAGE 1	kWh/m^3
STAGE 2	kWh/kg $TSS_{removed}$
STAGE 3	kWh/kg $COD_{removed}$, kWh/kg$TP_{removed}$
	kWh/kg $TN_{removed}$, kWh/kg$NH4_{removed}$
STAGE 4	kWh/kg $TSS_{removed,}$ kWh/kg$NH4_{removed}$
	kWh/kg $TN_{removed}$, kWh/kg$TP_{removed}$
	kWh/Log $_{reduction}$
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 $_{removed}$

ENERWATER methodology: Measure



ENERWATER methodology: Measure

Chemical energy as a key performance indicator

The use of chemicals and respective amounts can impact on the pollutants removal efficiency of WWTPs. In order to account for the use of chemicals on the ENERWATER methodology, the chemical "energy for production" for chemicals is also considered

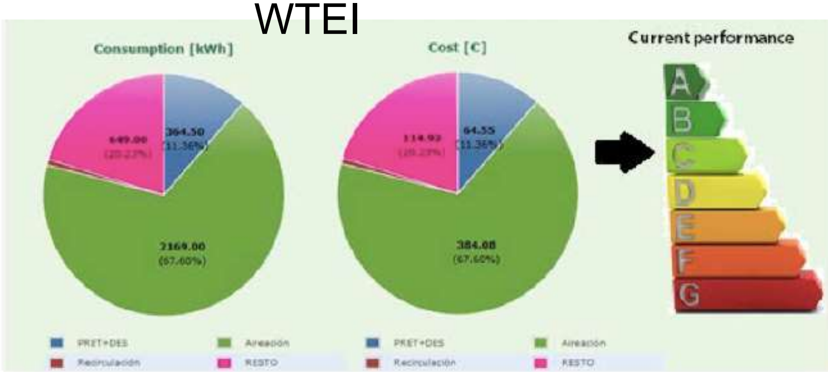
	Cumulative energy demand (CED) (kWh/kg)
Iron sulfate	1
Iron chloride	4.25
Alumn	3.78
Poly-electrolite	10.1
Acetic acid	15.1
Methanol	10
Sodium hydroxide	5.18

ENERWATER methodology: Analyze

Calculation of Energy Performance Index from KPIs

Communication
Water Treatment Energy Index - WTEI

DATA TREATMENT



Diagnosis
Which stages are less efficient?

ENERWATER methodology

	Rapid Audit Methodology	Decision Support Methodology
Energy consumption data	• Aggregated energy consumption from energy bills	• Disaggregated online data from energy meters on site
Plant operation data	• Historical influent/effluent characteristics	• Intra-sectional influent/effluent data
Objective	• Energy benchmark • Rapid tool to energy efficiency assessment	• Diagnosis • Understanding • Verification • Training toll
Human resources	• Trained auiditor/operator	• Required approvals, communications and health safety considerations • Training of auditors • Collaboration between electriciatian, operators, eng. department
Time frame	• 3 years historical data	???

WWTPs classification according to function

Key European Directives linked wastewater effluent discharges into waterways:

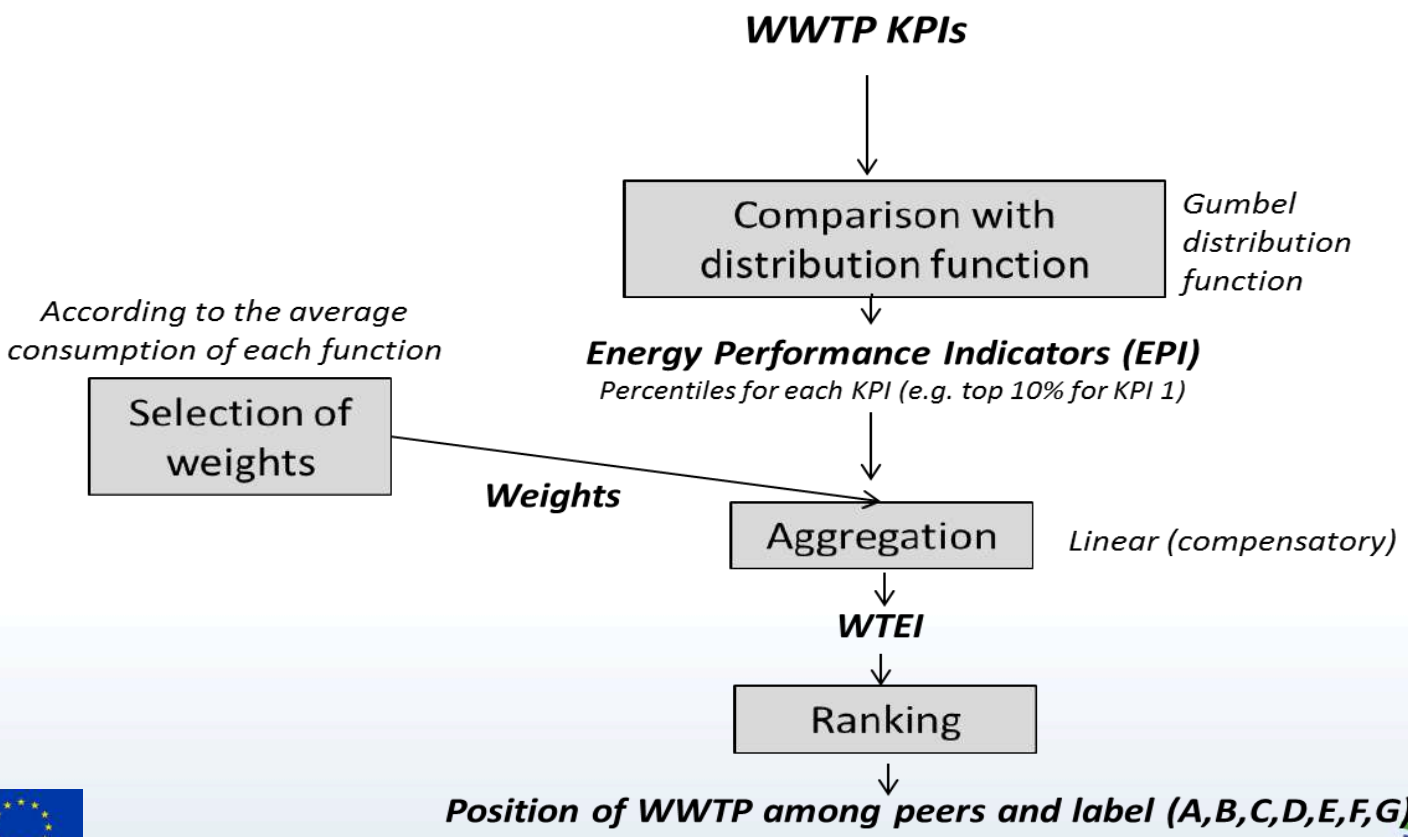
- Urban Waste Water Treatment Directive (UWWTD) (91/271/EEC)
- Nitrates Directive (ND) (91/676/EEC)
- Water Framework Directive (WFD) (2000/60/EC)
- Bathing Water Treatment Directive (2006/7/EC) replacing (76/160/EEC)
- Shellfish Directive (79/923/EEC)
- Freshwater Fish Directive (78/659/EEC)

- **Type 1: Discharge to non-sensitive** - this includes WWTPs focused on the removal TSS, BOD, COD and NH_4
- **Type 2: Discharge to sensitive areas** - this includes WWTPs focused on removing TSS, BOD, COD, total phosphorus, NH_4 and NO_3
- **Type 3: Discharge for re-use (pathogens)** - this includes WWTPs focused on removing TSS, BOD, COD, total phosphorus, NH_4, NO_3 and pathogens

Rodriguez-Garcia et al. (2011) *Water Res* 45, 5997

Rapid Audit Methodology

Rapid Audit Calculation of WTEI



Rapid Audit Methodology

Step 1: KPI estimation

Estimate the KPIs for the plant based on global energy consumption historical data

Use equation 1 to determine the total pollution equivalent removed and determine KPI_2 in $kWh/kgTP_{rem}$

KPI overall plant	Average	Std. deviation	90 percentile (P_{90})	10 percentile (P_{10})	Number of data
kWh/m^3	**0.700**	**0.684**	**1.488**	**0.173**	**470**
$kWh/kgCOD_{rem}$	1.819	2.267	3.553	0.569	470
$kWh/kgTN_{em}$	49.57	245.9	86.32	8.919	470
$kWh/kgTP_{rem}$	165.2	439.1	268.7	41.49	470
kWh/kgTPE	**0.414**	**0.300**	**0.779**	**0.172**	**470**
kWh/kgTSS	**3.907**	**4.79**	**11.39**	**0.782**	**50**

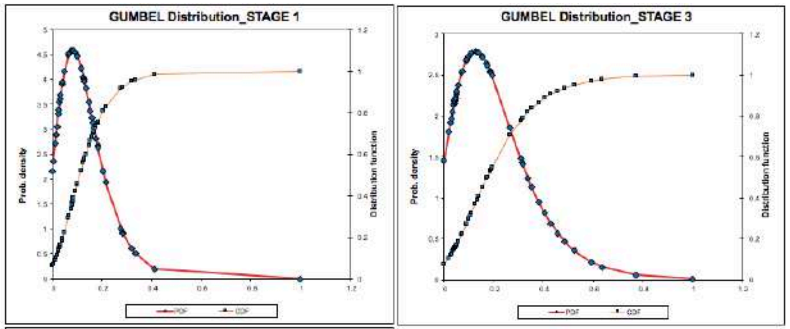
kg_{TPE} (total pollution equivalent) = $kg_{COD} + 20\ kg_{TN} + 100\ kg$ Equation 1

Benedetti et al, 2008

Rapid Audit Methodology

Step 2: KPI normalization

Compare the value of the KPIs with the database distribution function and obtain the percentile for each KPI using equations 3, 4 and 5. The percentile is a normalized manner to express the performance of the plant for a given KPI. Therefore, they are denominated energy performance indicators (EPI)



$$\text{For } KPI_1 \left(\frac{kWh}{m^3}\right) \qquad EPI_1 = Percentile\ (\%) = \exp\left(\exp\left(\frac{KPI_1 - 0.4513}{0.3674}\right)\right) x100 \qquad \text{Equation 3}$$

$$\text{For } KPI_2 \left(\frac{kWh}{kgTP_{rem}}\right) \qquad EPI_2 = Percentile\ (\%) = \exp\left(\exp\left(\frac{KPI_2 - 0.3001}{0.1731}\right)\right) x100 \qquad \text{Equation 4}$$

$$\text{For } KPI_3 \left(\frac{kWh}{kgTSS}\right) \qquad EPI_3 = Percentile\ (\%) = exp\left(exp\left(\frac{KPI_3 - 2.1509}{2.3872}\right)\right) x100 \qquad \text{Equation 5}$$

Rapid Audit Methodology

Step 3: Weight selection

Choose the weights for the selected KPIs from table 4. These weights have been estimated based on the average contribution of each function of the WWTP to the overall energy consumption, i.e. pumping accounts for approximately 14.25% of the overall energy consumption and the secondary treatment (removal of COD and nutrients) accounts for the 70%
If not all the KPIs are considered in the analysis, the weights are normalise to ensure that their sum is equal to one.

KPI	KPI_1 (kWh/m^3)	KPI_2 ($kWh/kgTPE_{rem}$)	KPI_3 (kWh/kgTSS)	KPI_4 (kWh/logReduction)
Value (w_i)	0.1425	0.7005	0.1133	0.0406

weights obtained from our database
50 WWTPs

If the four KPIs are not applicable, normalise the weights to sum unity such as:

$$w_{norm,i} = \frac{w_i}{\sum_1^k w_i}$$ where k is the number of applicable KPIs

Rapid Audit Methodology

Step 4: Aggregation

Aggregate the EPI into a single WTEI through a weighted sum (Equation 7). This method of aggregation is compensatory, i.e. one EPI can compensate to a certain extent the performance in other functions

$$WTEI = \sum_{i=1}^{k} w_{norm,i}\, EPI_i$$

Rapid Audit Methodology

Step 5: Rank and label assignation

The boundaries between labels have been decided according to the following criterion, common in EU efficiency labelling standards: the median performance index is the upper boundary of class D. This labelling strategy allows good discrimination power at high efficiency, serving as an incentive for innovation.

Label	WTEI
A	<0.11
B	0.11≤WTEI<0.22
C	0.22≤WTEI<0.33
D	0.33≤WTEI<0.44
E	0.44≤WTEI<0.55
F	0.55≤WTEI<0.75
G	<0.75

Case study: Define

	Plant A	Plant B	Plant C
ENERWATER Typology	3	2	3
Capacity	25,000 PE	9,360 PE	48,000 PE
Pre-treatment	Coarse screening, grit and grease removal	Storm water tank, coarse screening, grit and grease removal	Fine screening, grit and grease removal
Primary treatment	-	Primary sedimentation	-
Secondary treatment	Oxidation ditch and secondary sedimentation	Activated sludge and secondary sedimentation	Activated sludge + chemical P precipitation and secondary sedimentation
Tertiary treatment	UV disinfection	-	Filtration, UV disinfection
Sludge Treatment	Thickening, dewatering and landfill disposal	Thickening, dewatering, disposal	Thickening, dewatering, disposal

Case study: Define

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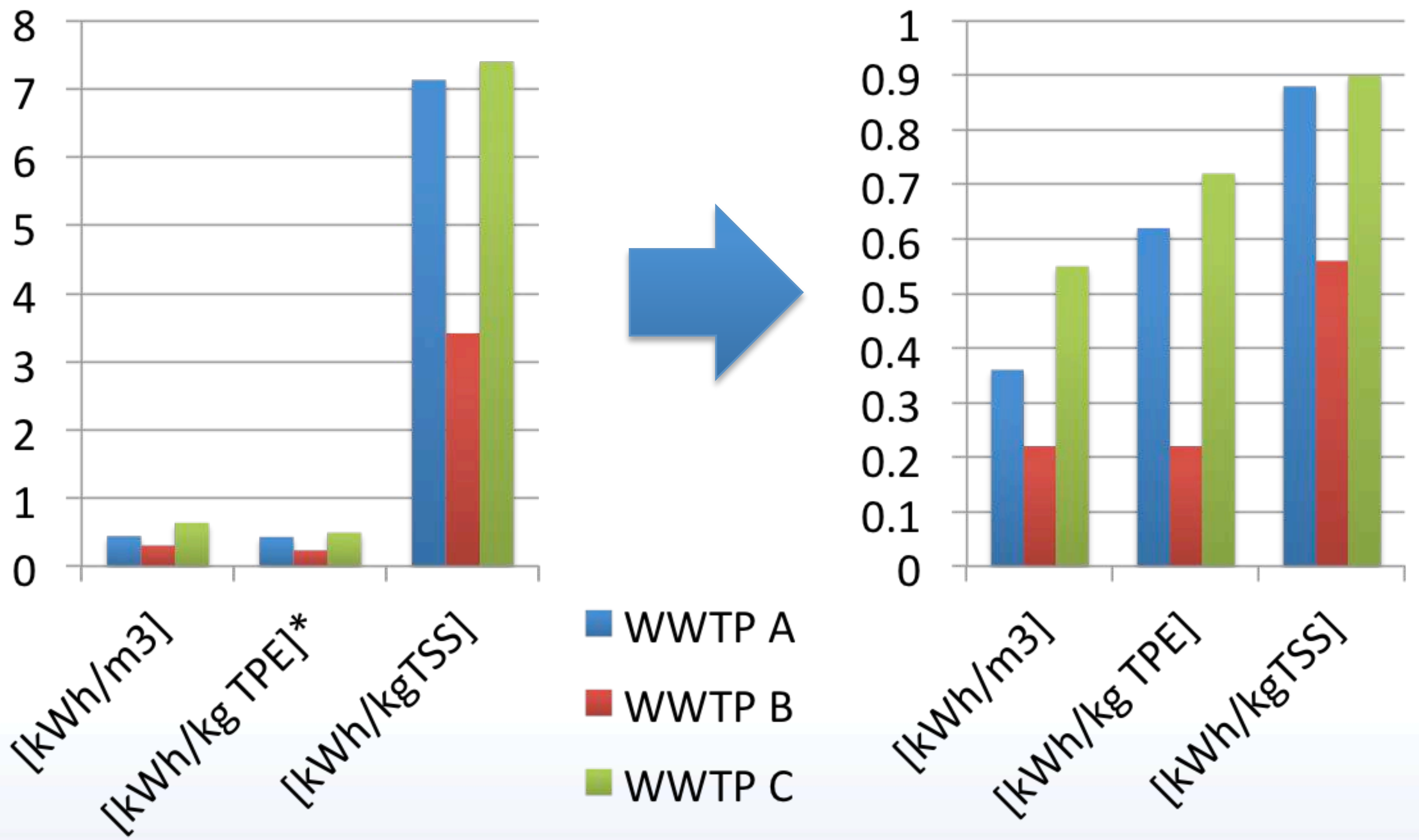
Case study: Measure

Energy carrier	WWTP A	WWTP B	WWTP C
Electric energy [kWh]	759,321	522,557	769,016
Natural gas [Scm]	-	-	-
Biogas [Scm]	-	-	-
Chemicals [kWh]	1,503	18,497	55,006
Total energy [kWh]	759,534	541,054	824,022

	WWTP A		WWTP B		WWTP C	
Parameter	Influent	Effluent	Influent	Effluent	Influent	Effluent
Flow [m^3]	1,730,329		1,791,271		5,760,845	
COD [mg/L]	255.00	50.00	305.53	10.40	308.00	22.00
TN [mg/L]	22.00	4.00	30.06	0.06	36.60	6.40
TP [mg/L]	7.20	2.60	4.63	0.46	4.63	0.57

Case study: Analyze



Case study: Final WTEI

WWTP A

Label:

F

WTEI:

0.61

WWTP B

Label:

C

WTEI:

0.26

WWTP C

Label:

F

WTEI:

0.71

Conclusions

The application of the ENERWATER Rapid Audit methodology to benchmark and audit the municipal WWTPs advanced the current state of the art and allowed:

- the comparison among heterogeneous WWTPs based on the basic functions of a plant
- the disaggregation of the key performance indicators based on these functions
- the definition of single WTEIs and energy labels (classes A to G) that can support the decisions of the water utilities to best target of energy saving actions to less performing WWTPs

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To know more

Longo et al. 2016. Applied Energy, 179, 1251

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Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Monitoring and diagnosis of energy consumption in wastewater treatment plants. A state of the art and proposals for improvement

Stefano Longo[a], Benedetto Mirko d'Antoni[b], Michael Bongards[c], Antonio Chaparro[d], Andreas Cronrath[c], Francesco Fatone[b], Juan M. Lema[a], Miguel Mauricio-Iglesias[a], Ana Soares[e], Almudena Hospido[a,*]

Contact details

@EnerwaterPro

Enerwater Project Linked in

www.enerwater.eu

stefano.longo@usc.es

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A STANDARD METHOD AND ONLINE TOOL FOR ASSESSING AND IMPROVING THE ENERGY EFFICIENCY OF WASTEWATER TREATMENT PLANTS

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Thank you!

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