Universitat Autònoma de Barcelona

The European Water Platform

Agència Catalana de l'Aigua

Depuración de Aguas del Mediterráneo

Two-stage autotrophic N-removal for mainstream sewage treatment

Eficiencia energética en EDARs. Proyecto Europeo Enerwater

Stefano Longo
Universidad de Santiago de Compostela

How to define energy efficiency at WWTP?

Energy efficiency is normally defined as the relationship between
the consumption of energy and
the production of a service

$\frac{\text{Input}}{\text{Output}}$

Input → **Energy**
(electricity, diesel, gas, chemicals)

Output → **Energy service**
(pumping, TS removal, nutrient removal, pathogen removal, sludge handling etc.)

ENERWATER

National guidelines:

- In Italy: kWh/m^3
- In Germany: kWh/PE·y

Applied Energy 179 (2016) 1251–1268

Contents lists available at ScienceDirect

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,*]

[a] Department of Chemical Engineering, Institute of Technology, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Spain
[b] Department of Biotechnology, University of Verona, Strada Le Grazie 15, 37134 Verona, Italy
[c] Cologne University of Applied Sciences, Research group GECO-C, Steinmüllerallee 1, 51643 Gummersbach, Germany
[d] Wellness Smart Cities, Calle Charles Darwin, 41092 Sevilla, Spain
[e] Cranfield Water Science Institute, Cranfield University, Cranfield, Bedfordshire MK43 0AL, UK

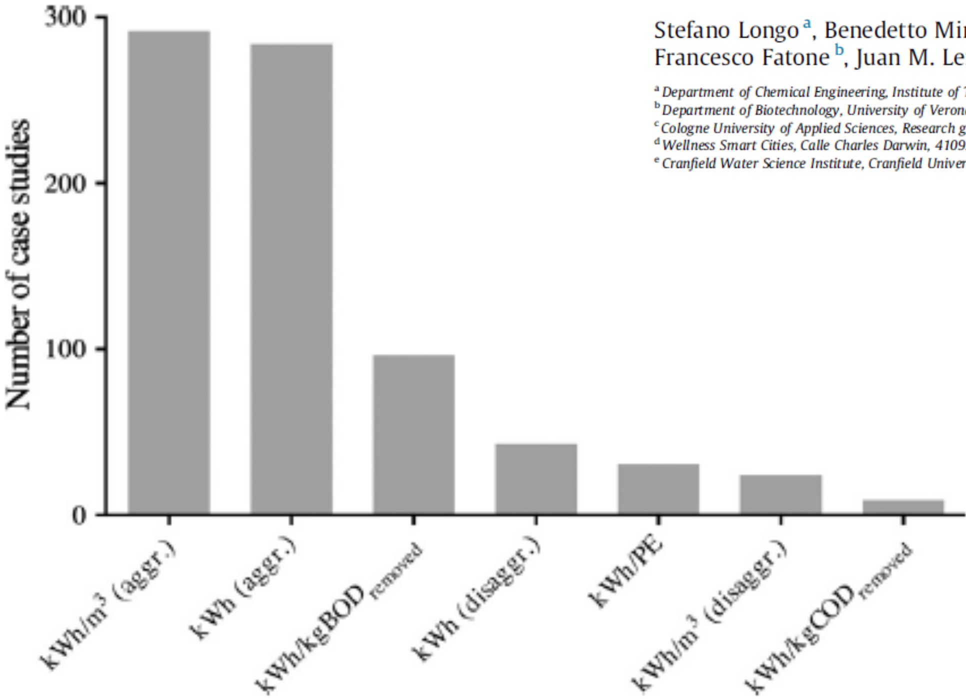
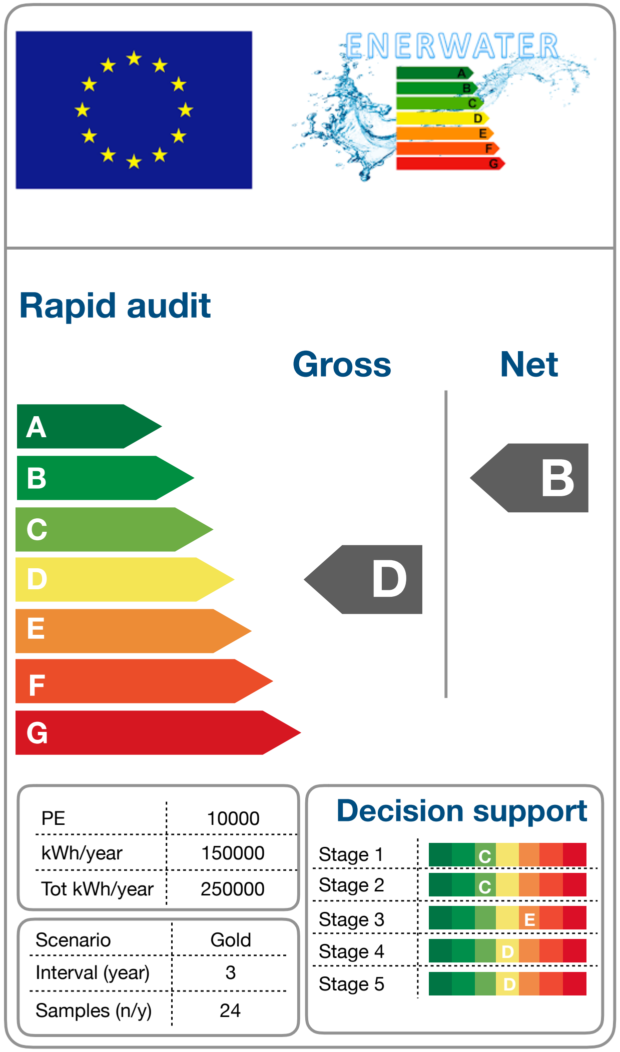


Fig. 2. Statistics frequencies of how energy data are reported in the literature. Aggr. = aggregated data; disaggr. = disaggregated data.

WWTPs energy benchmarking methods applied so far in the wastewater sector:
-Data Envelopment Analysis (DEA)
-USEPA Energy Star method for WWTPs
can be used for comparison but they fail at prescribing any improvement strategy

The final goal…



Universally understood energy label

Water Treatment Energy Index (WTEI)

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.

ENERWATER Project

The main objective is to develop, validate and to disseminate an innovative standard methodology for continuously assessing, labelling and improving the overall energy performance of Wastewater Treatment Plants (WWTPs)

44 months (March 2015 – October 2018)

1.7 MM €

Universidade de Santiago de Compostela (ES)

Università degli Studi di Verona (IT)

Università Politecnica delle Marche, Ancona

University of Cranfield (UK)

Technical University of Cologne (DE)

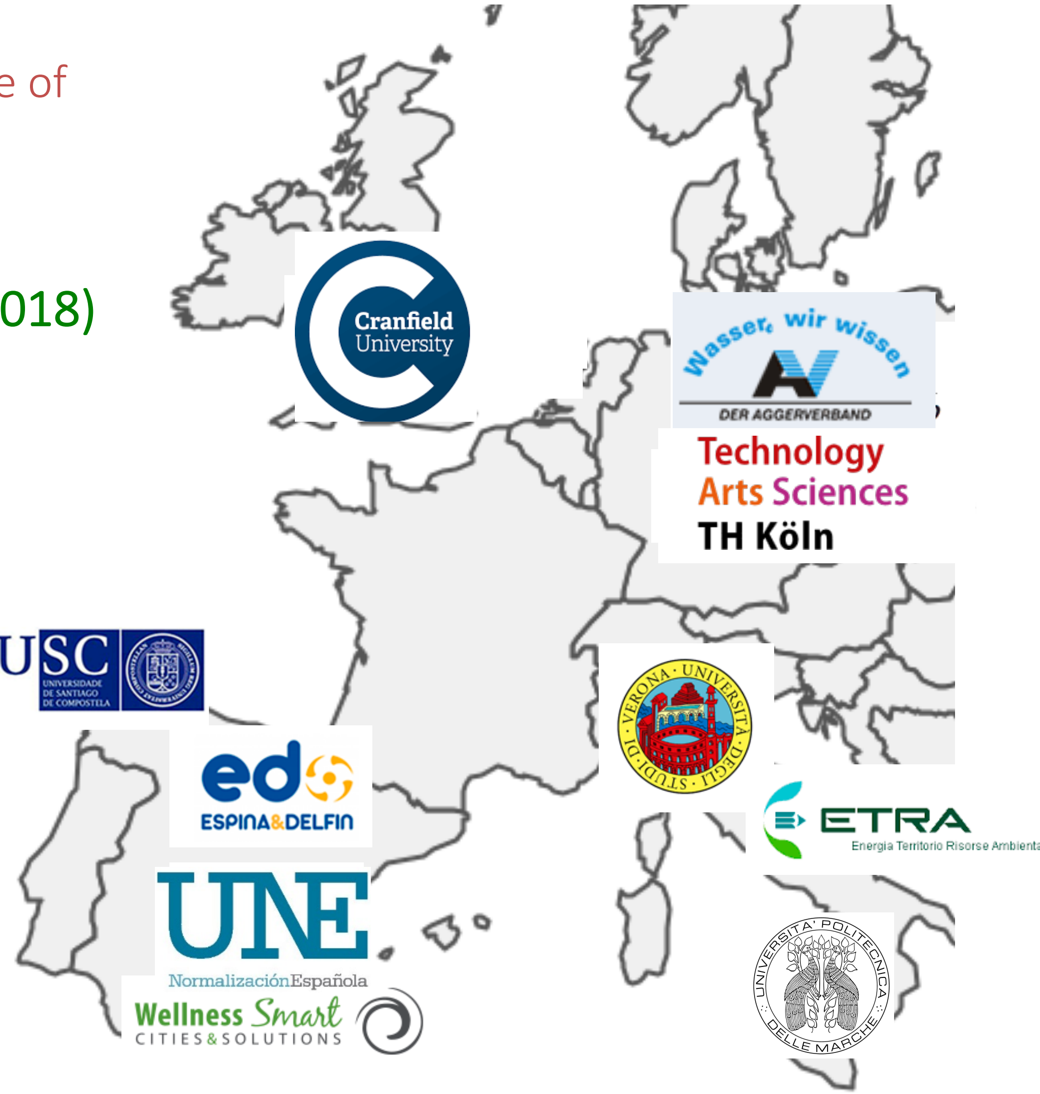
Espina y Delfín (ES)

ETRA (IT)

Aggerverband (DE)

UNE (ES)

Wellness Smart Cities (ES)



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** areas - 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

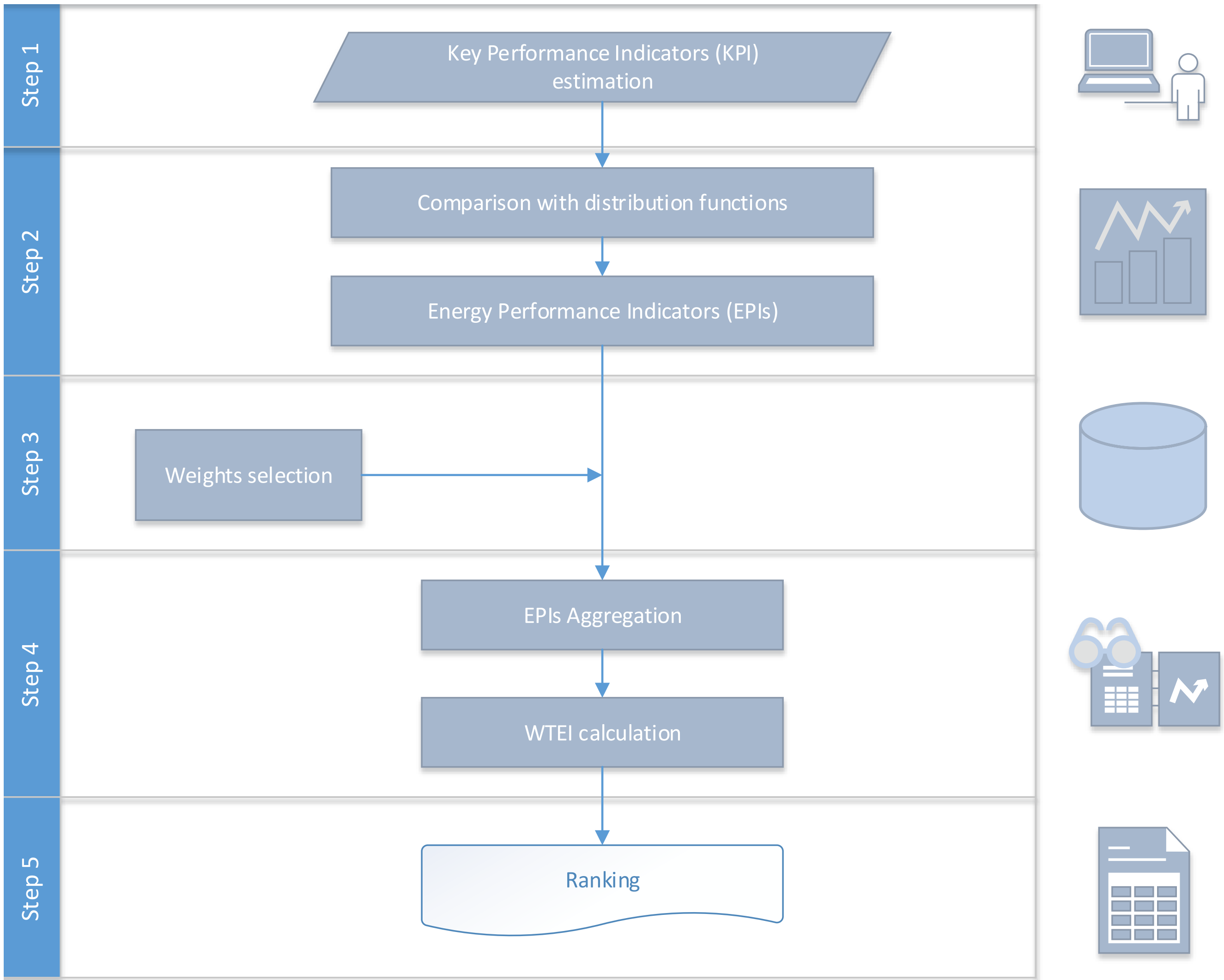
Other factors that influence performance

- Sludge import
- Various types of energy used (electricity, diesel, gas etc.)
- Chemicals used (chemical energy consumption – obtained from Ecoinvent database)
- Renewable energy produced at WWTP: Gross and Net energy consumption

2 Tools: Rapid Audit and Decision Support

	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	• Routine (available) influent/ effluent analyses	• Intra-sectional influent/effluent data
Objective	• Energy benchmarking • Rapid tool to energy efficiency assessment	• Diagnosis • Verification • Training tool

Water Treatment Energy Index (WTEI) calculation



Data collection and KPIs calculation

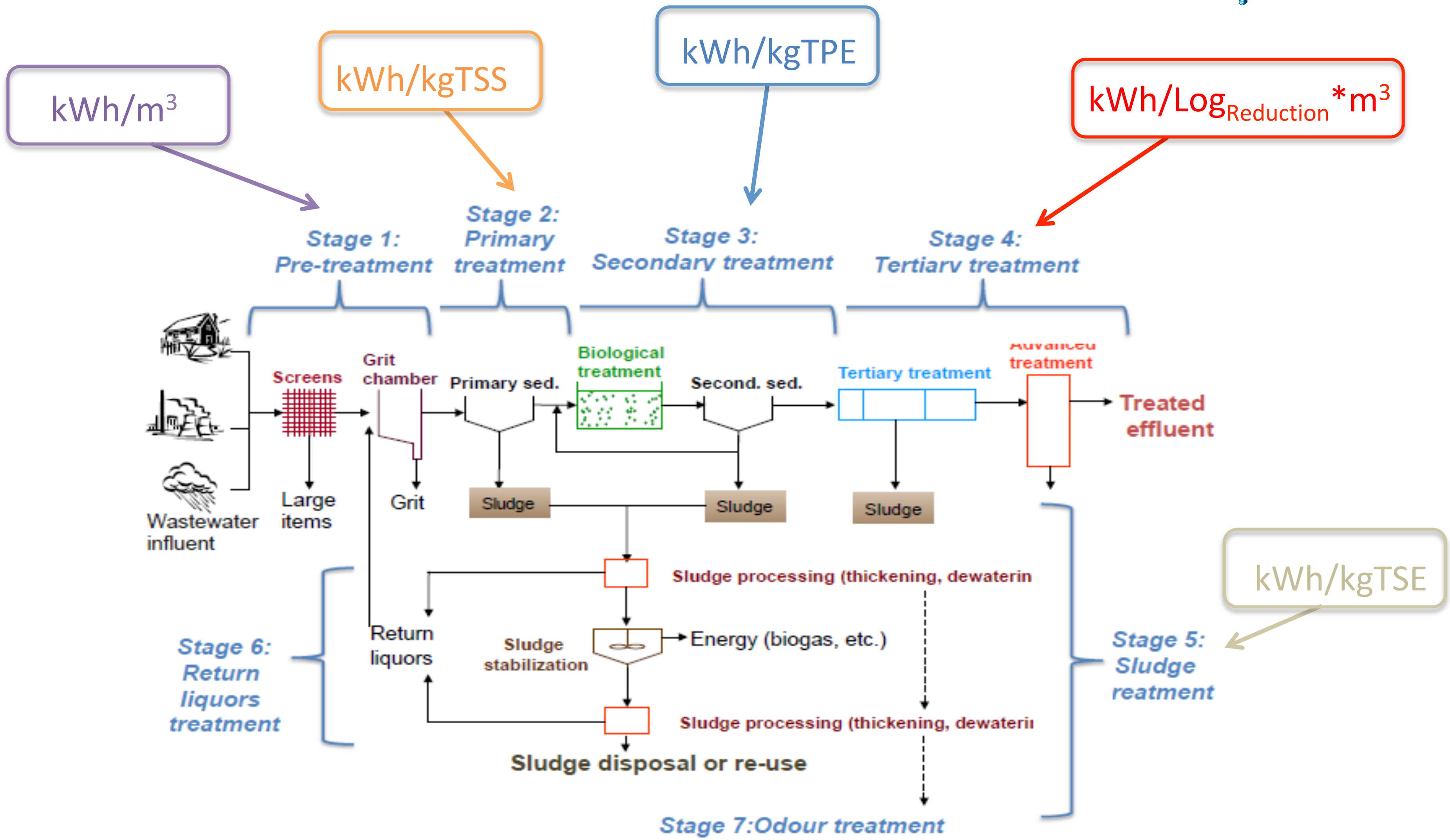
Compare the value of the KPIs with distribution functions and obtain percentile of each KPIs (EPIs)

Choose the weights for the selected KPIs from database of WWTPs energy consumption data

Aggregate the EPIs into a single WTEI through a weighted sum

Assign label corresponding to the value of the WTEI

Step 1: KPI determination



ENERWATER Methodology: Define

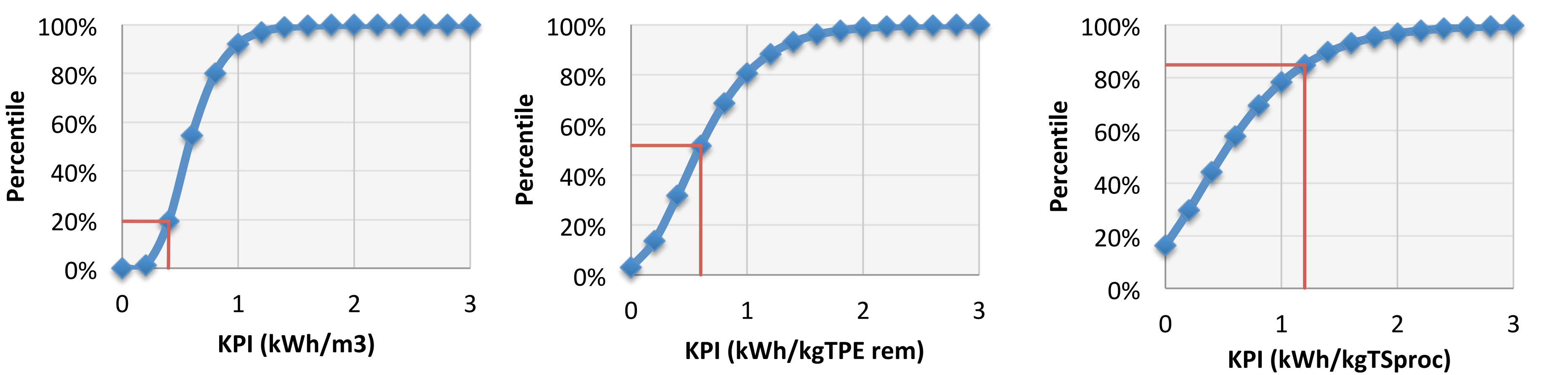
There is a clear need to establish suitable KPIs within the WWTP that allow a comparable, realistic and universal form of reporting the energy data.

STAGE	FUNCTION	KPI
STAGE 1	Pumping	kWh/m^3
STAGE 2	Solid removal	$kWh/kg\ TSS_{removed}$
STAGE 3	Pollutants removal	$kWh/kg\ TPE_{removed}$ *
STAGE 4	Pathogens removal	$kWh/Log_{reduction} * m^3$
STAGE 5	Sludge handling	$kWh/kg\ TS_{processed}$

* kgTPE (total pollution equivalent) = kgCOD+20 kgTN+100 kgTP
Benedetti et al. 2008

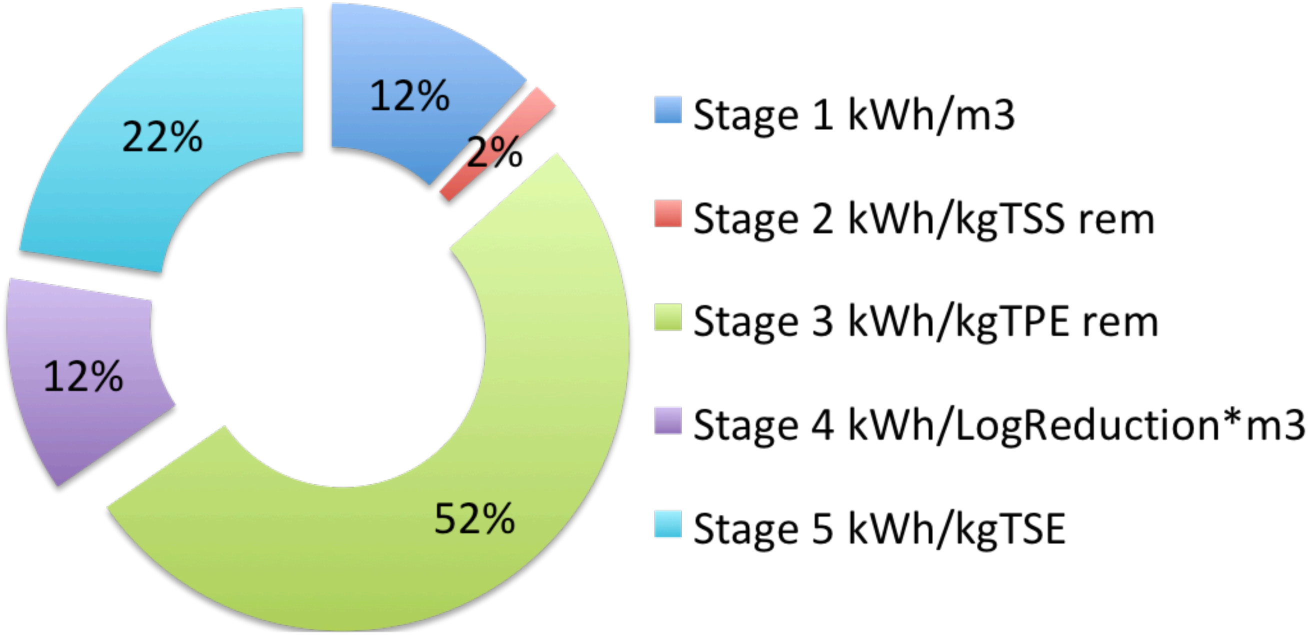
Step 2: KPI normalization

- Compare the value of the KPIs with the database distribution function and obtain the percentile for each KPI.
- 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)



Step 3: Weight selection

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 12% of the overall energy consumption and the secondary treatment (removal of COD and nutrients) accounts for the 52%.



If the five 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

Step 4: Aggregation

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

$$WTEI_c = \sum_{i=1}^{k} w_{norm,i} \times EPI_{i,c}$$

Normalized KPI value

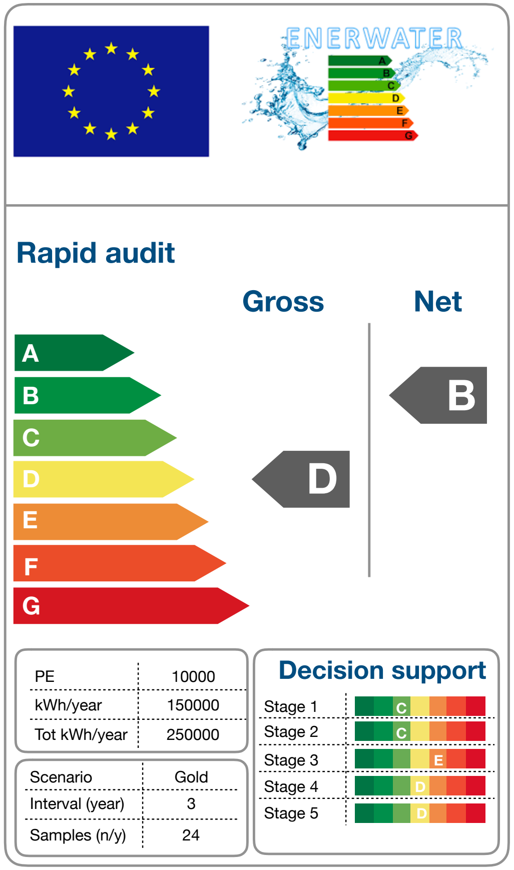
Composite indicator value for plant c

Weight value for KPI k

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.

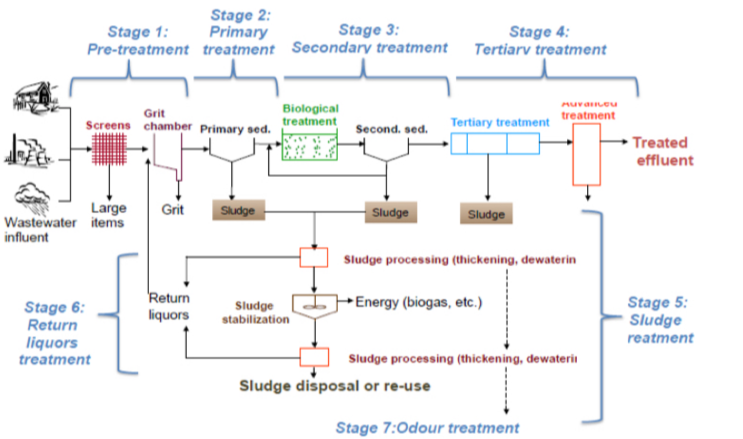
Label	WTEI
A	<0.11
B	0.11≤WTEI<0.22
C	0.22≤WTEI<0.33
D	0.33≤WTEI<0.44
E	0.44≤WTEI<0.55
F	0.55≤WTEI<0.75
G	>0.75



Overview of the ENERWATER methodology

Check the energy consumption and determine the KPIs

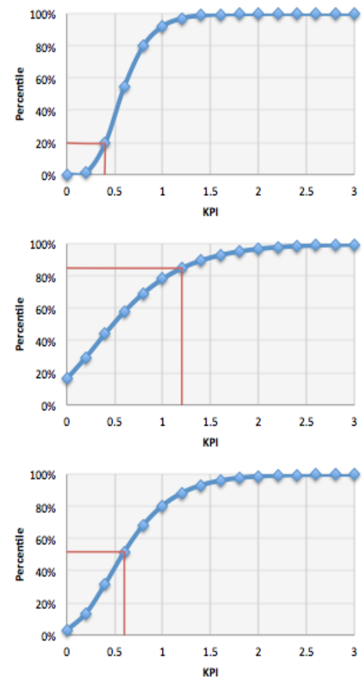
$$KPI_1 = \frac{kWh}{m^3 \text{ of water treated}} \quad KPI_2 = \frac{kWh}{\text{kg solids removed}} \quad KPI_3 = \frac{kWh}{\text{kg pollutant removed}} \quad KPI_4 = \frac{kWh}{(m^3 \cdot \text{log reduction of pathogens})}$$



$$KPI_6 = \frac{kWh}{\text{kg nitrogen removed}} \quad KPI_7 = \frac{kWh}{\text{kg volatile organic compound}} \quad KPI_5 = \frac{kWh}{\text{kg sludge treated}}$$

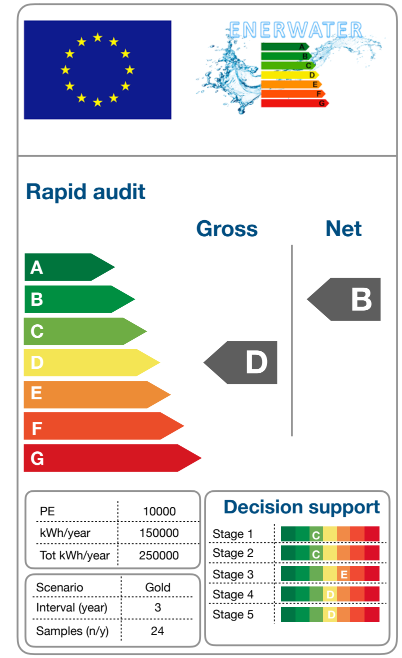
WWTP divided into functions -> a KPI is associated to each function performance

Compare vs other WWTPs



Assign a percentile to each KPI with a 600 WWTPs database

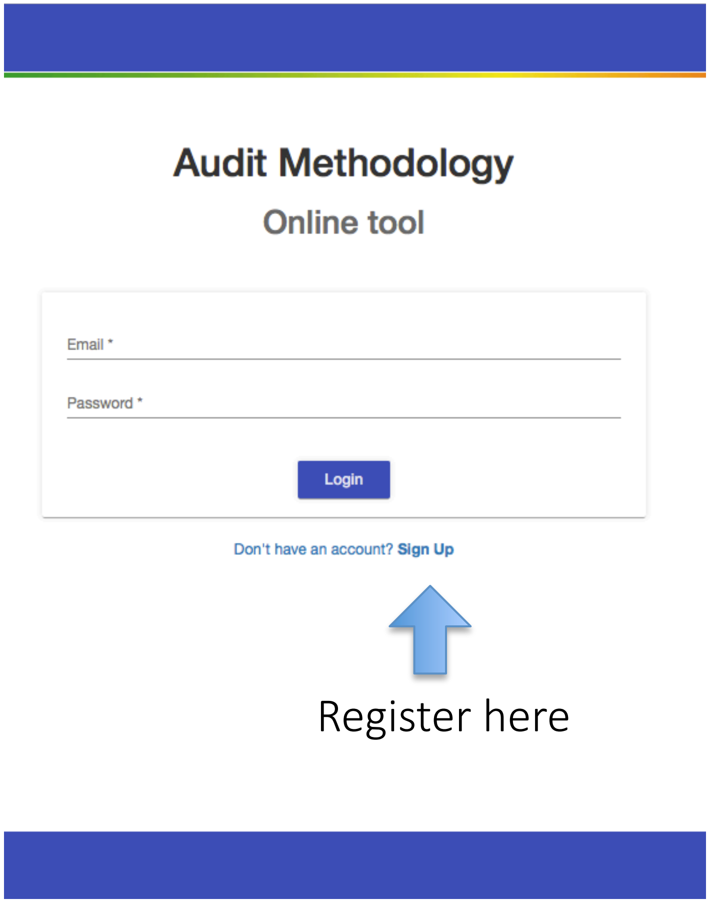
Get the energy label

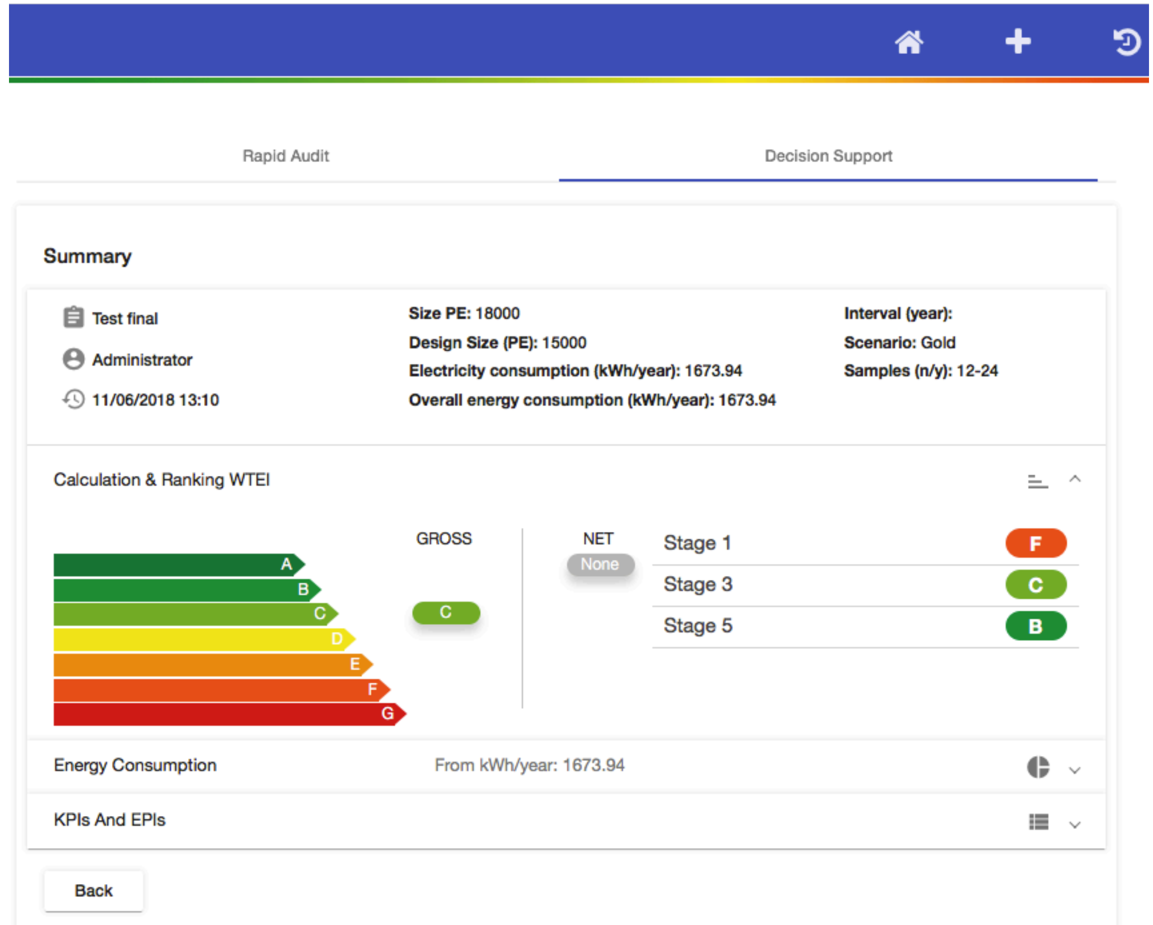


Diagnosis of inefficient processes. Communication through the energy label

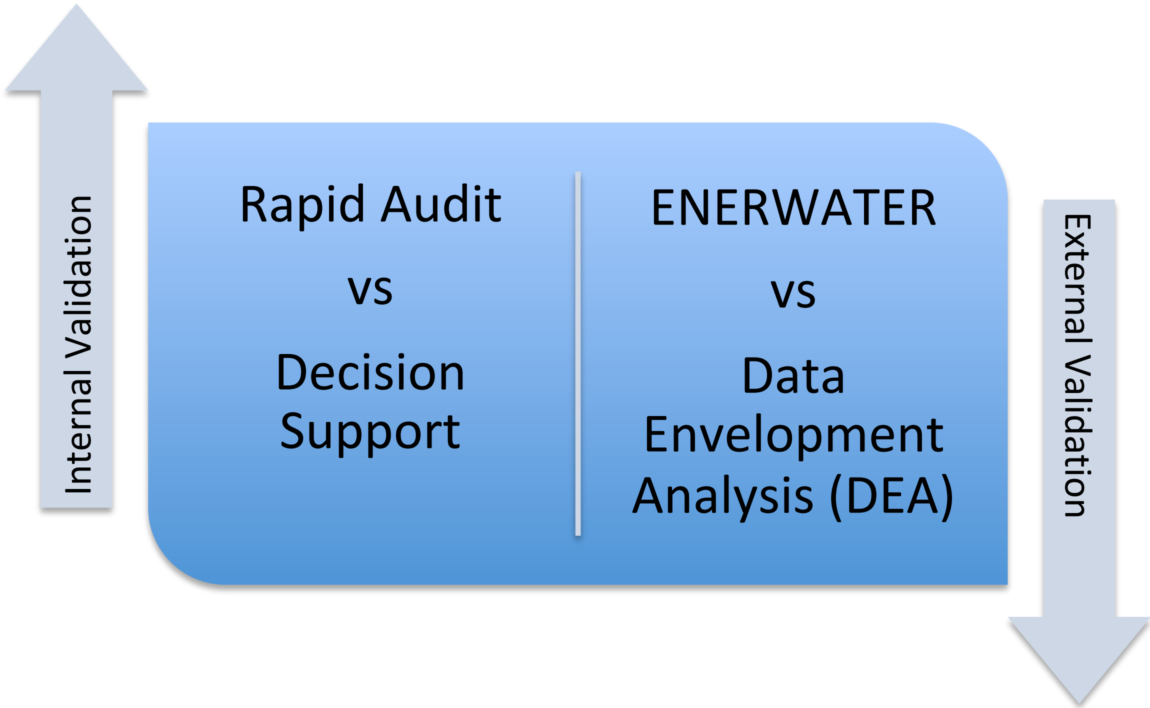
ENERWATER online tool is (almost) ready to use

ENERWATER methodology: http://www.enerwater.eu/download-documentation/
ENERWATER online tool: https://enerwater-h2020.wtelecom.es





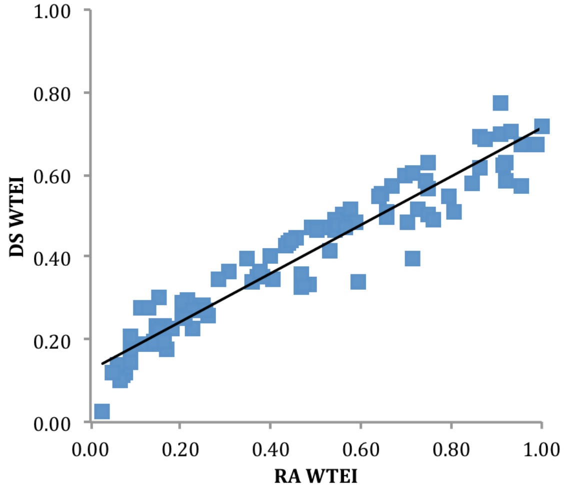
ENERWATER methodology validation

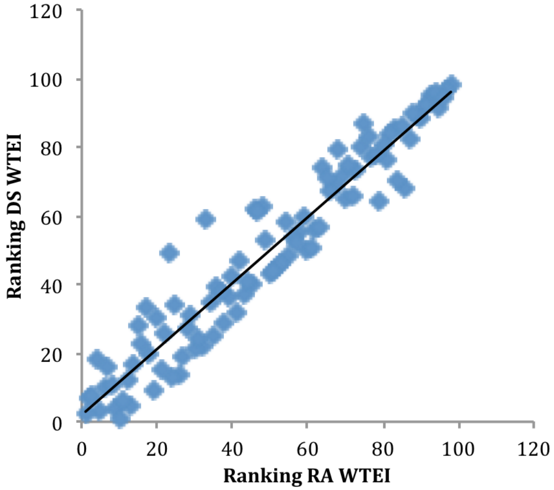


The cross-examination consists in checking three consistency conditions for the efficiency measures:

- the efficiency scores generated by the different approaches should have comparable means, standard deviations, and other distributional properties;
- the different approaches should rank the WWTPs in approximately the same order;
- the different approaches should identify mostly the same WWTPs as "best-practices" and as "worst-practices".

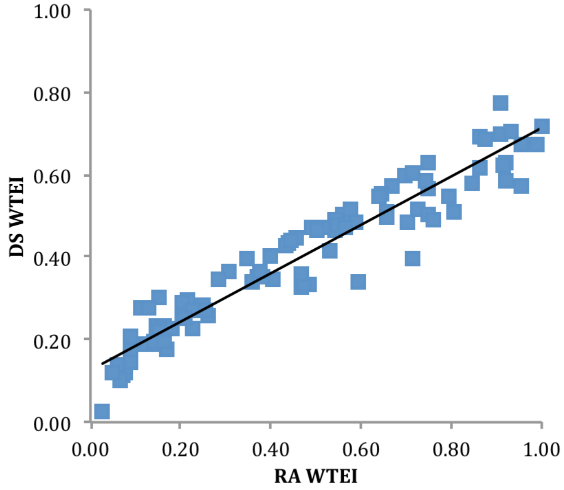
Internal validation: ENERWATER Rapid Audit vs Decision support:

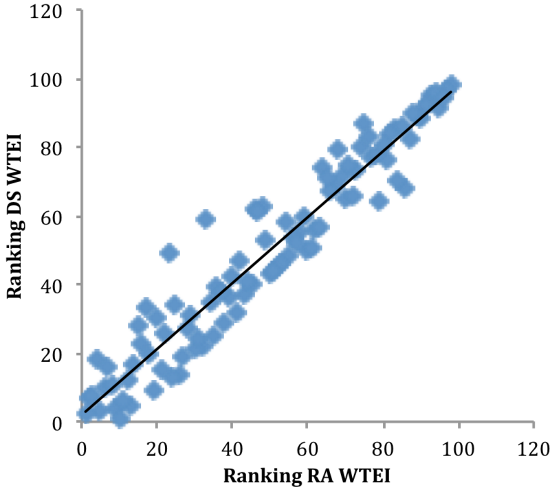




Correlation higher than 90%

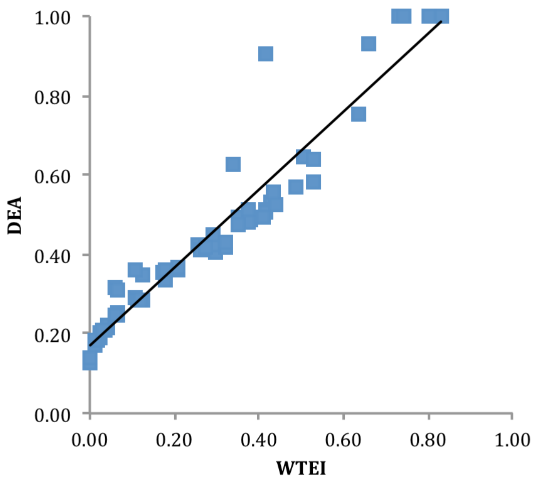
Internal validation: ENERWATER Rapid Audit vs Decision support:

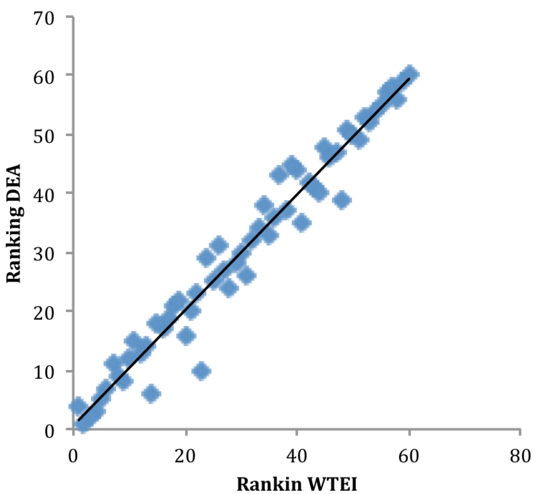




Correlation higher than 90%

External validation: ENERWATER vs Data Envelopment Analysis





Correlation higher than 90%

Case study

	Plant 1	Plant 2	Plant 3
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, bio-P removal, secondary sedimentation	Activated sludge + chemical P precipitation, secondary sedimentation	Activated sludge + chemical P precipitation, secondary sedimentation
Tertiary treatment	-	-	UV disinfection
Sludge Treatment	Thickening, dewatering and disposal	Thickening, dewatering, disposal	Thickening, dewatering, disposal

Energy data:

Energy carrier	WWTP 1	WWTP 2	WWTP 3
Electric energy [kWh/d]	759,321	522,557	769,016
Natural gas [Scm/d]	-	-	-
Biogas [Scm/d]	-	-	-
Chemicals [kWh/d]	1,503	18,497	55,006
Total energy [kWh/d]	759,534	541,054	824,022

Operational data:

	WWTP 1		WWTP 2		WWTP 3	
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

Rapid Audit analysis: which plant is inefficient?

	WWTP 1	WWTP 2	WWTP 3
Label	C	B	F

- Plant 3 is a good candidate to for implementing energy saving measures.
- Where does inefficiency come from???

Case study

Rapid Audit analysis: which plant is inefficient?

	WWTP 1	WWTP 2	WWTP 3
Label	C	B	F

- Plant 3 is a good candidate to for implementing energy saving measures.
- Where does inefficiency come from???

Decision Support analysis: which function of a plant is inefficient?

	WWTP 1	WWTP 2	WWTP 3
Stage 1	F	B	G
Stage 2	-	C	-
Stage 3	C	C	F
Stage 4	-	. -	G
Stage 5	B	B	A
Global Label	C	B	F

- Plant 1 and 3 should look at their pumping station
- Plant 3 has very likely a low efficient aeration system, as well as low efficient UV lamp

ENERWATER is proposing a new standard for WWTP energy efficiency

ENERWATER methodology

Technical report

European standard

Preparing report jointly with Working Group 40

To be voted by CEN/TC-165 members

Towards an European Standard

Standardization activities in ENERWATER:

- Analysis of the state of the art (Deliverable 5.2 Standardization landscape)
- Contact with stakeholders in the search for feedback and consensus
- Communication with the standardization technical committees
- Proposed normative document
- (European Technical Report, CEN / TR)

Benefits:

- Promote a common method applicable to the most common WWTPs in Europe
- Facilitate the acceptance and use by the market of the defined methodology
- Help optimize WWTP management and service provision, thus reducing costs
- Open a way to progressively introduce aspects of energy efficiency in other sector standards already published

To know more…

ENERWATER

Contents lists available at ScienceDirect
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,*]

[a] Department of Chemical Engineering, Institute of Technology, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Spain
[b] Department of Biotechnology, University of Verona, Strada Le Grazie 15, 37134 Verona, Italy
[c] Cologne University of Applied Sciences, Research group GECO-C, Steinmüllerallee 1, 51643 Gummersbach, Germany
[d] Wellness Smart Cities, Calle Charles Darwin, 41092 Sevilla, Spain
[e] Cranfield Water Science Institute, Cranfield University, Cranfield, Bedfordshire MK43 0AL, UK

- Energy data and main approaches for energy benchmarking
- Main factors affecting energy demand at WWTPs
- Dataset of 600 WWTPs

Contents lists available at ScienceDirect
Water Research
journal homepage: www.elsevier.com/locate/watres

A systematic methodology for the robust quantification of energy efficiency at wastewater treatment plants featuring Data Envelopment Analysis

S. Longo[*], A. Hospido, J.M. Lema, M. Mauricio-Iglesias

Department of Chemical Engineering, Institute of Technology, Universidade de Santiago de Compostela, 15782 Santiago de Compostela, Spain

- External effects (e.g. temperature, size, load factor, dilution, technology)
- Extended dataset (available upon request)
- Methodology for including external variable in the analysis (Matlab code available upon request)

SEEC Surrey Energy Economics Centre — USC — University of Surrey

Comparative energy efficiency of wastewater treatment plants based on economic foundations

41ST IAEE INTERNATIONAL CONFERENCE GRONINGEN 2018

Stefano Longo[1,2]
Mona Chitnis[2]
Miguel Mauricio-Iglesias[1]
Almudena Hospido[1]

- Energy demand model for WWTPs
- Panel data
- Is inefficiency due to the operation or to the equipment?

ENERWATER

Acknowledgements & Disclaimer:
The ENERWATER project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 649819 (H2020-EE-2014-3-MarketUptake). Although the project's information is considered accurate, no responsibility will be accepted for any subsequent use thereof. The EC accepts no responsibility or liability whatsoever with regard to the presented material, and the work hereby presented does not anticipate the Commission's future policy in this area.

THE FRAMEWORK PROGRAMME FOR RESEARCH AND INNOVATION HORIZON 2020

www.enerwater.eu ENERWATER Project @EnerwaterPro

Universitat Autònoma de Barcelona

The European Water Platform

Agència Catalana de l'Aigua

Depuración de Aguas del Mediterráneo

Two-stage autotrophic N-removal for mainstream sewage treatment

Eficiencia energética en EDARs. Proyecto Europeo Enerwater

Stefano Longo

Universidad de Santiago de Compostela