Italian National Agency for New Technologies, Energy and Sustainable Economic Development

A methodology for benchmarking of energy consumption in municipal wastewater treatment plants

Dott. Gianpaolo Sabia
Ing. Luigi Petta

ENEA Division Resource Efficiency
Laboratory USER-T4W Technologies for the efficient use and management of water and wastewater

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Generic methodological aspects

Objectives: Classification, benchmarking and labelling of WWTPs on the basis of the energy consumptions.

The methodology resorts to the **use of statistical techniques** requiring **input data** for:

- **analyzing WWTP energy performances** on the basis of the calculation of *Key Performance Indicators* (***KPIs***) and the linear aggregation of the related informative content in a *Global Energy Index* (***GEI***).
- **evaluating WWTP energy balance efficiencies** by carrying out comparative analysis with ***sectorial data used as reference***;
- **classifying WWTPs** according to the definition of **performance efficiency classes.**
- estimating potential margins for **energy performance improvements**.

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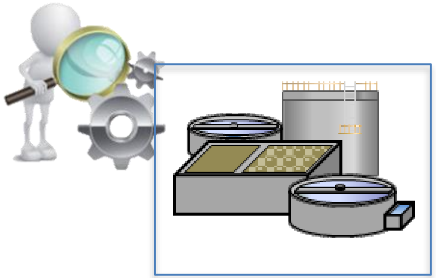
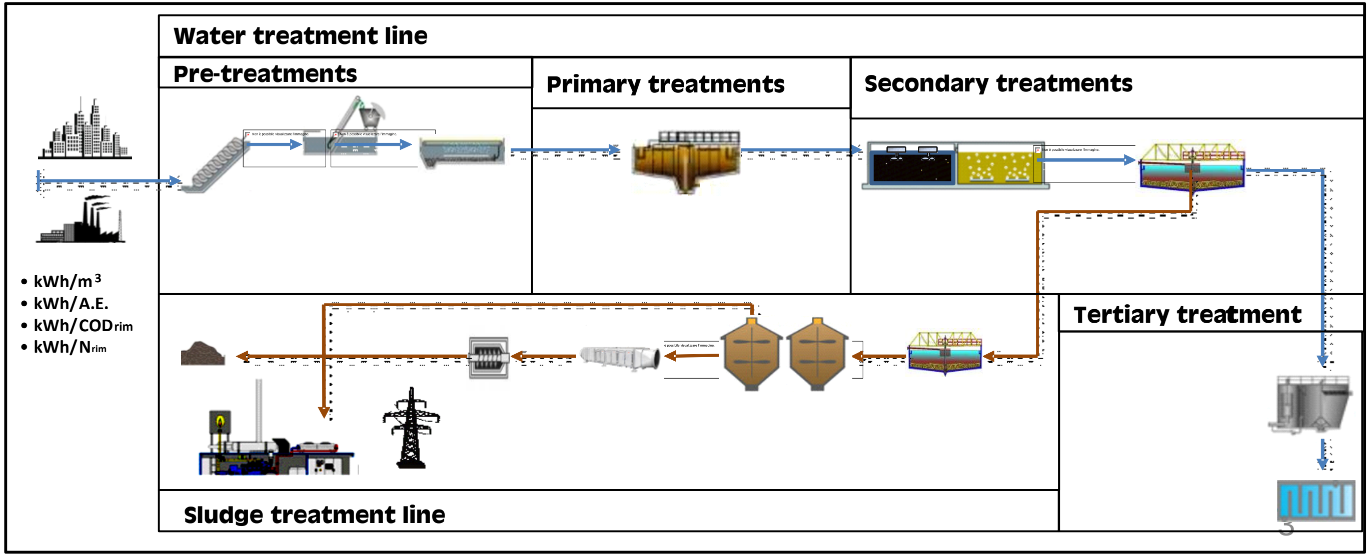
Premises on applicable approaches and data sources: top-down and bottom-up models

a) The **top-down** approach provides a global overview (*at aggregated level*) of the energy consumptions of the systems and requires *minimum data inputs.*

b) For the WWTP sector, data on WWTP global energy consumptions are generally available (from electricity bills, sales, direct POD readings) as well data on plant size, inner and output volumetric loads, pollutant loads and removal rates.

Weak point: these data deliver typically no information about energy uses (i.e. where and for what?).



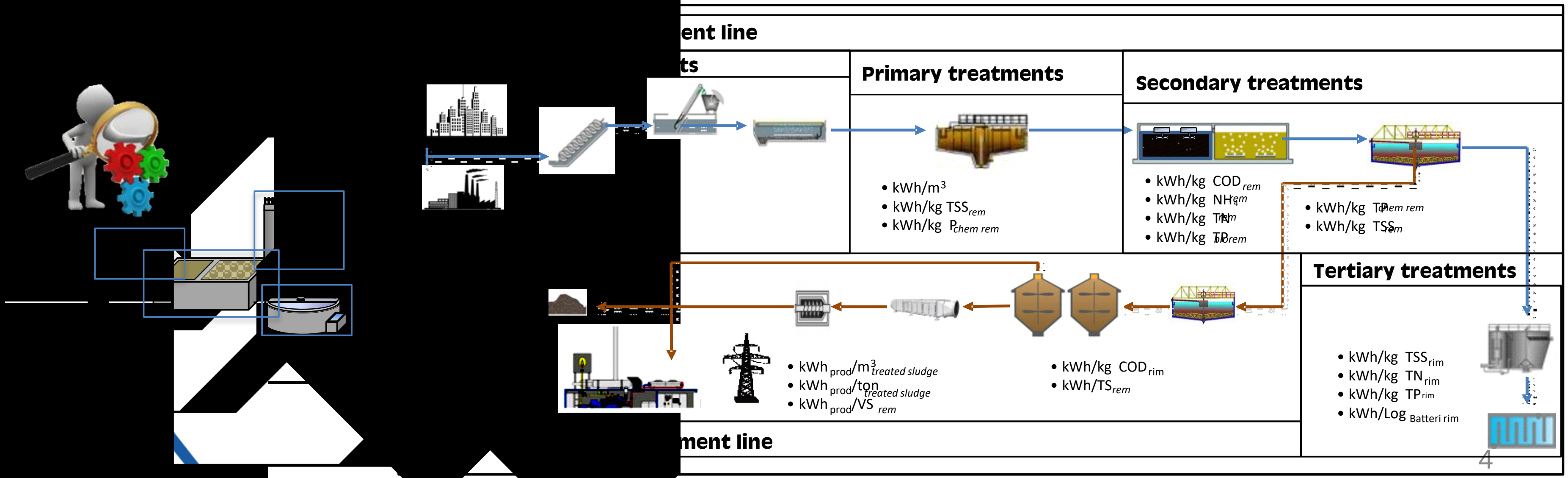


Premises on applicable approaches and data sources: top-down and bottom-up models

b) The **bottom-up** approach is based on the calculation of the energy use of each component or plant section, but it is far *data-demanding* and requires the carrying out of specific on-site measurements [redacted] and time.

[redacted]ific energy consumptions of plant sections or technologies/processes [redacted]ches.

[redacted]*lity to build a reference database for benchmarking.*



Methodological approach and steps *(1)*:

- Adoption of a **top-down approach** (larger data availability) by using global KPIs calculated relating the WWTP energy use to influent flow rates, plant design capacity, organic loads and removal rates.

- Definition of a **reference data-base** collecting data on WWTP energy consumptions at national and European level (i.e. 250 WWTPs);

WWTP ID	Energy	Size	Volumetric loads	Organic loads	KPI_1	KPI_2	KPI_1
ID 01							
ID02							

ID_n							

- **KPIs calculation**:

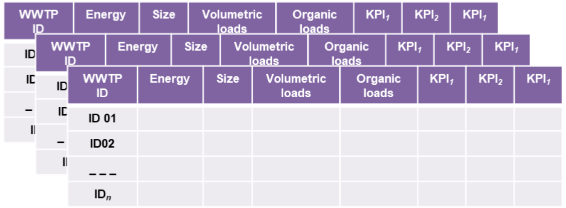
$$KPI_1 = E.E./V_{in} (kWh/m^3)$$

$$KPI_2 = E.E./P.E. (kWh/P.E.*y)$$

$$KPI_3 = E.E./COD_{rem} (kWh/kgCOD_{rem})$$

- Data normalization according to a min-max criteria.

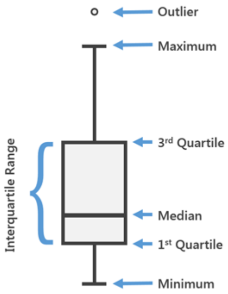
- Subset data organization according to a plan size criteria (5 sub-matrices):



ID≤2k P.E.; 2k<ID≤10k P.E.; 10k<ID≤50k P.E.; 50k<ID≤200k P.E.; ID>200kP.E.

- Application of **statistical analysis techniques** for the **validation and control of source data** with the deletion of multivariate outliers

  Applied tests: Mahalanobis distance and the *Chauvenet's criterion*



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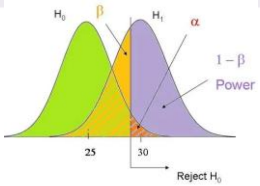
Methodological approach and steps *(2)*:

WWTP ID	Energy	Size	Volumetric loads	Organic loads	KPI_1	KPI_2	KPI_1
ID 01							
ID02							
– – –							
ID_n							

- Verification of the **applicability of Factorial Analysis (FA)** to the sub-matrices for KPI weighting factors calculation.

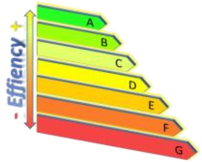
Applied tests:
Bartlett's test of sphericity
Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO).



- Calculation of **the Global Energy INDEX (GEI)** by linearly aggregating KPIs.

$$GEI = \Sigma w_i * KPI_i.$$

- Ranking and definition of **efficiency energy classes** on the basis of the GEI distributions for labelling on **classes A to G.**



The methodology has been **validated evaluating** the correspondence of results a WWTP lists reported in in ENERWATER project (Horizon 2020, 2015/18) Deliverable 3.4 Evaluation Report: Rapid Audit.

WWTP ID	KPI_1	KPI_2	KPI_3	GEI	Rank	Label
ID01						D
ID_n						B

	WTEI Enerwater	Rank	Label
ID01			D
ID_n			A

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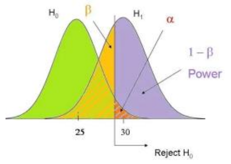
Case study applied to 10 selected ID_{cs} WWTPs:

Principal steps applied (retracing the procedure):

WWTP ID	Energy	Size	Volumetric loads	Organic loads	KPI_1	KPI_2	KPI_i
ID 01							
ID02							

ID_n							

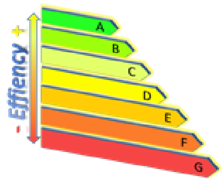
- Definition of a **Check list** and data requested to water utilities operators.
- Monthly data (for 1 year) elaborated to **calculate of KPI values.**
- Insertion of ID_{cs} into the reference database and matrix normalization.
- Reorganization of the matrix into the defined sub-matrices.



- **Weights definition** by means FA and aggregation of KPIs for **GEIs calculations**.

$$GEI = \Sigma w_i * KPI_i.$$

- WWTP **ranking** on the basis of GEI values.
- Definition of the **energy classes** according to GEI ranges.
- Labelling of the WWTPs.



Results for size plant 10-50K P.E.

Statistical test results for the verification of the FA applicability to the sub-matrix:

Bartlett's spherical test verified for p-value <0.05;
KMO test verified for values> 0.5

Statistica tests
Bartlett's Test of Sphericity
p-value < 2.22e-16
Kaiser-Meyer-Olkin Statistics
KMO-Criterion: 0.675

Energy classes definition:

Interval ranges based on the GEI distribution median value and according to UNI EN ISO 52003-1:2018 .

	Classes
A	<0,04
B	0,04-0,08
C	0,08-0,11
D	0,11-0,15
E	0,15-0,19
F	0,19-0,23
G	>0,23

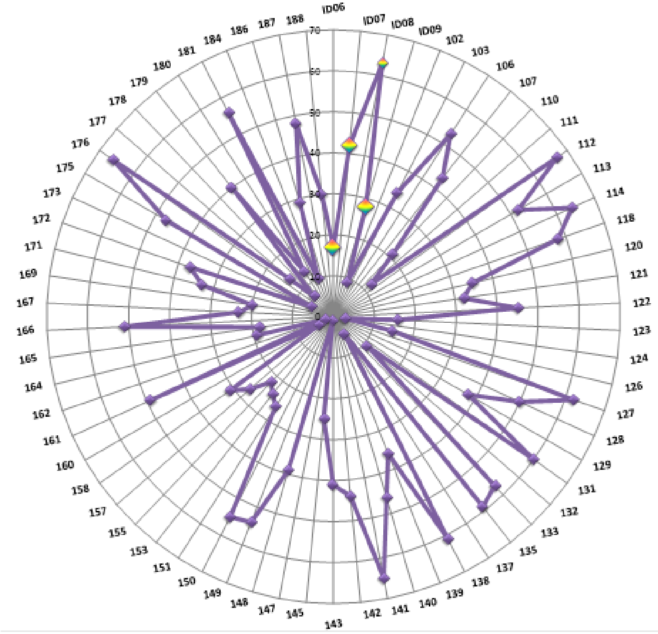
GEI values, ranking and labelling.

The method used to define the <u>ranking is in descending order</u>, so that in the lower positions are allocated ID with lower GEI index values corresponding to lower energy consumption.

	GEI	Rank ↓	Label 1
$ID_{cs}06$	0,11	17	C
$ID_{cs}07$	0,19	42	E
$ID_{cs}08$	0,38	63	G
$ID_{cs}09$	0,14	28	D
ID.Ref 5	0,08	9	C
ID.Ref 6	0,15	34	D
ID.Ref 7	0,26	53	G
ID.Ref 8	0,19	43	F
ID.Ref 70	0,12	21	D

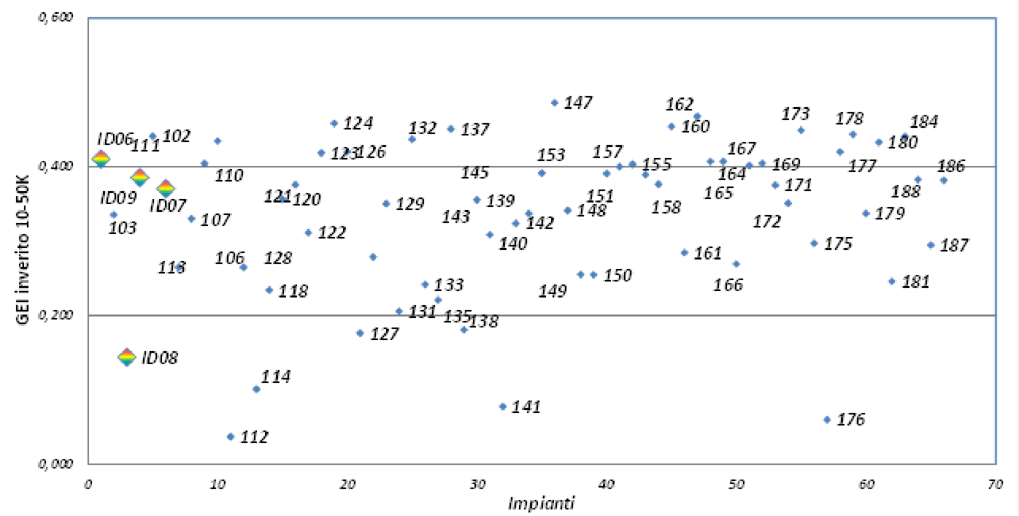
Results for size plant 10-50K P.E.

ID rankings in descending order



Inverted GEI Index values for IDs => The parameter is designed to detect performance differences between ID in terms of "distances"

<u>(ID with greater GEI_{inv} = better performance)</u>



ID_{cs} (<u>*in yellow*</u>) show a general disparate level of energy efficiency, in particular:

ID_{cs}08 reveals more critical issues (Rank = 63 of 66) with relative margins for energy efficiency recovery;

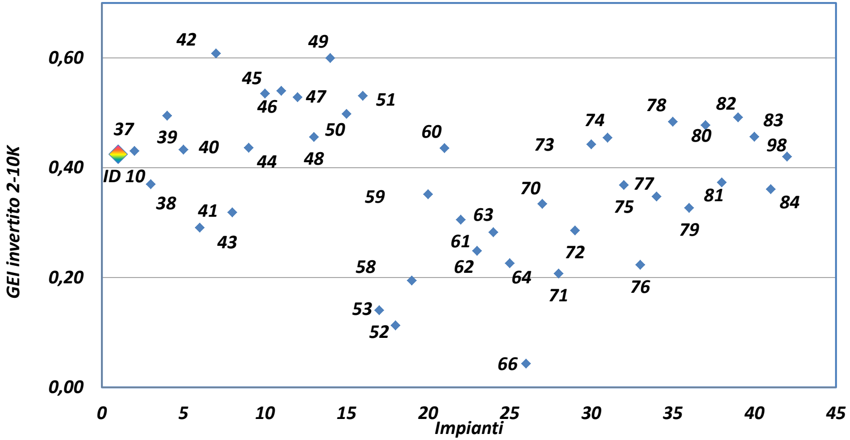
ID_{cs}06 results to be among the CS WWTPs the best performingt although the "distance" from the vertices.

Results for size plant 2-10K P.E.

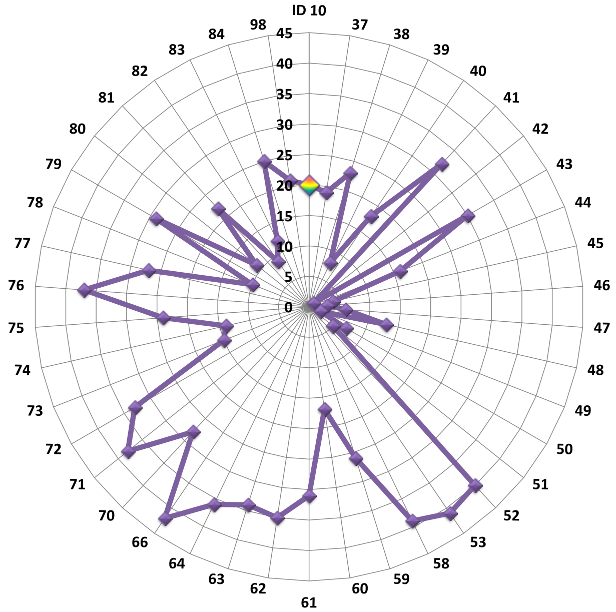
GEI values, ranking and labelling.

	GEI	Rank ↓	Label 1
ID$_{cs}$10	0,23	7	C
ID.Ref 2	0,22	6	C
ID.Ref 3	0,28	15	D
ID.Ref4	0,23	8	C
ID.Ref 43	0,31	22	E

Inverted GEI Index values for IDs



ID rankings in descending order



ID$_{cs}$10 <u>falls among the plants with lower energy consumptions</u>

The analysis of the GEI distribution shows that 36% of WWTPs have values lower than 25°percentile.

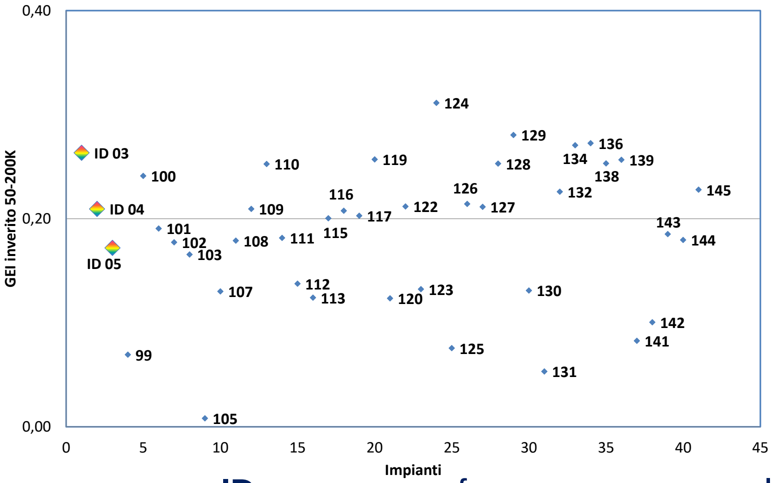
IDcs10 has energy performances comparable to the most of WWTPs.

Results for size plant 50-200K P.E.

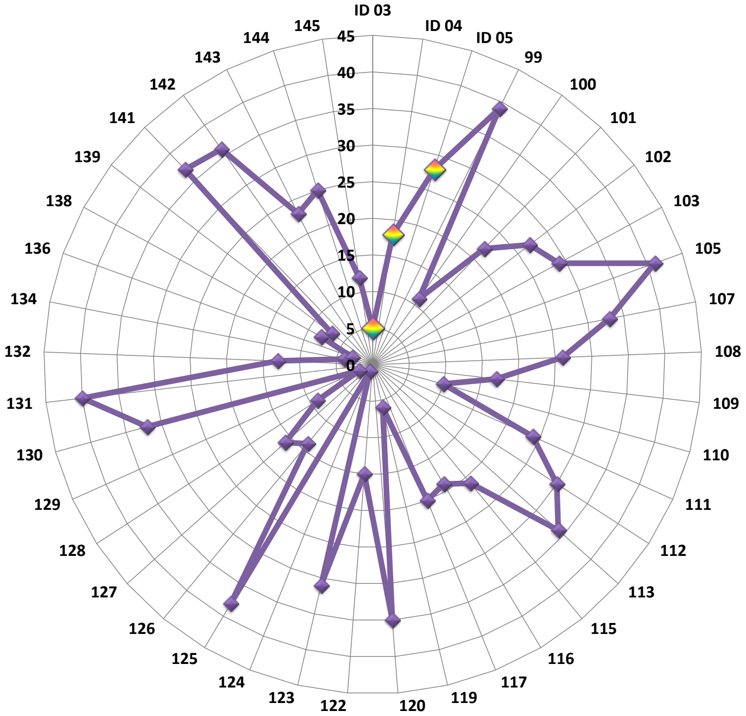
GEI values, ranking and labelling

	GEI	Rank ↓	Label 1
ID_{cs}03	0,06	5	B
ID_{cs}04	0,11	18	D
ID_{cs}05	0,15	28	E
ID.Ref 7	0,14	27	E
ID.Ref 41	0,15	29	E

Inverted GEI Index values for IDs



ID rankings in descending order



ID_{cs} energy performances are evenly distributed among WWTPs,

ID_{cs}03 showed good performances with a rank positioning as 5 of 46

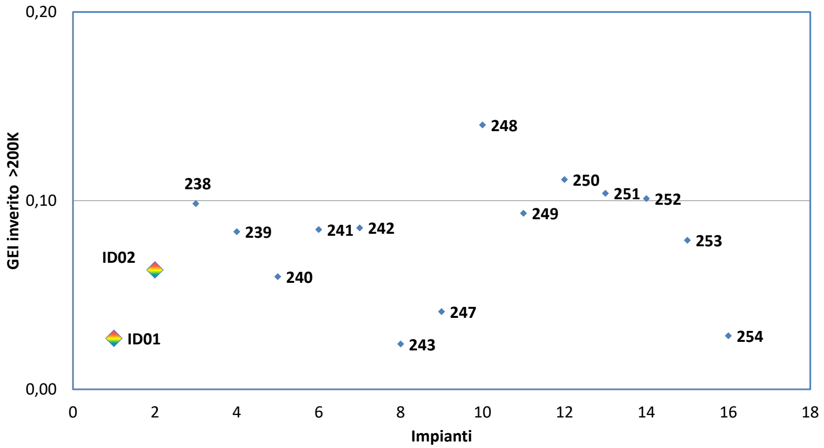
ID_{cs}04 and **ID_{cs}05** with a lower performance, suggest greater margings for energy balance improvements.

Results for size plant >200K P.E.

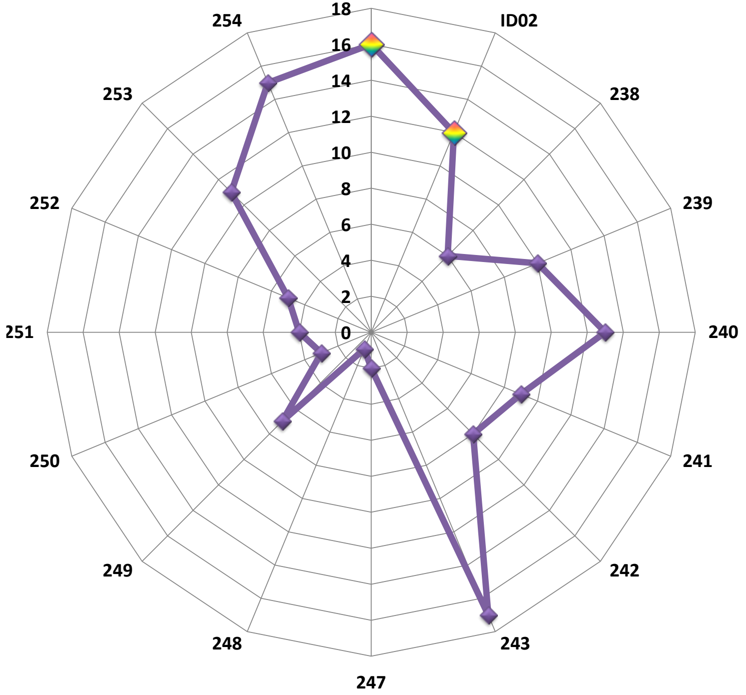
GEI values, ranking and labelling.

	GEI	Rank ↓	Label 1
$ID_{cs}01$	0,14	16	G
$ID_{cs}02$	0,10	12	F
ID.Ref 1	0,07	6	D
ID.Ref 2	0,08	10	E
ID.Ref 16	0,14	17	G

Inverted GEI Index values for IDs



ID rankings in descending order



$ID_{cs}01$ and $ID_{cs}02$ are not so energy performing.

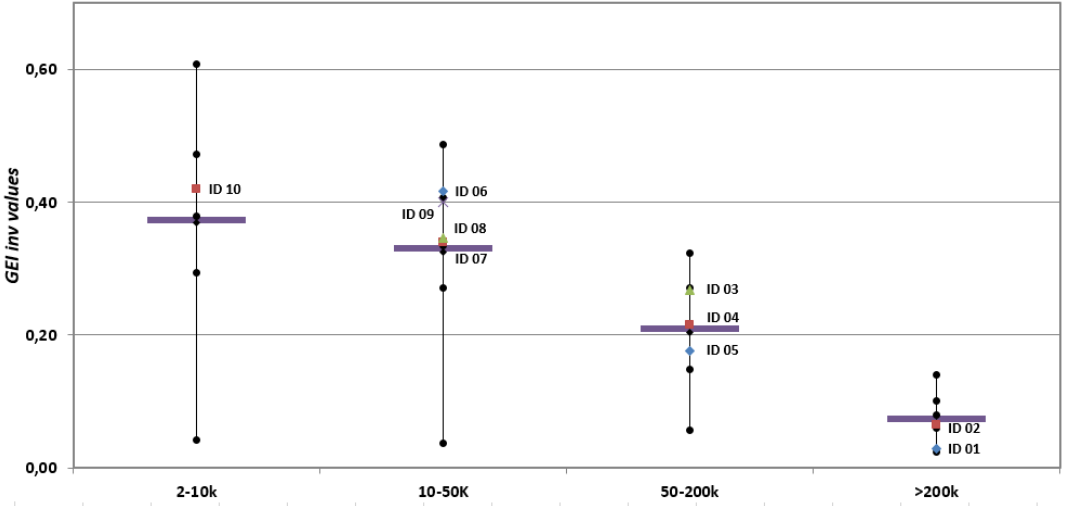
To take into account potential result distortions related to the sub-matrix database characteristics (16 WWTPs with potentiality up to 800 kP.E.)

Final results and Conclusions

Result summary

	GEI	GEI Range	Label	Rank ↓	n. WWTPs	Size (P.E.)
$ID_{cs}01$	0,14	0,02-0,14	G	16	17	>200k
$ID_{cs}02$	0,10		F	12		
$ID_{cs}03$	0,06	0,01-0,31	B	5	41	50-200k
$ID_{cs}04$	0,11		D	18		
$ID_{cs}05$	0,15		E	28		
$ID_{cs}06$	0,11	0,04-0,49	C	17	66	10-50K
$ID_{cs}07$	0,19		E	42		
$ID_{cs}08$	0,14		G	63		
$ID_{cs}09$	0,38		D	28		
$ID_{cs}10$	0,23	0,21-0,59	C	7	42	2-10k

Box Plot on GEI_{inv}- ID_{cs} positioning according to the energy efficiency



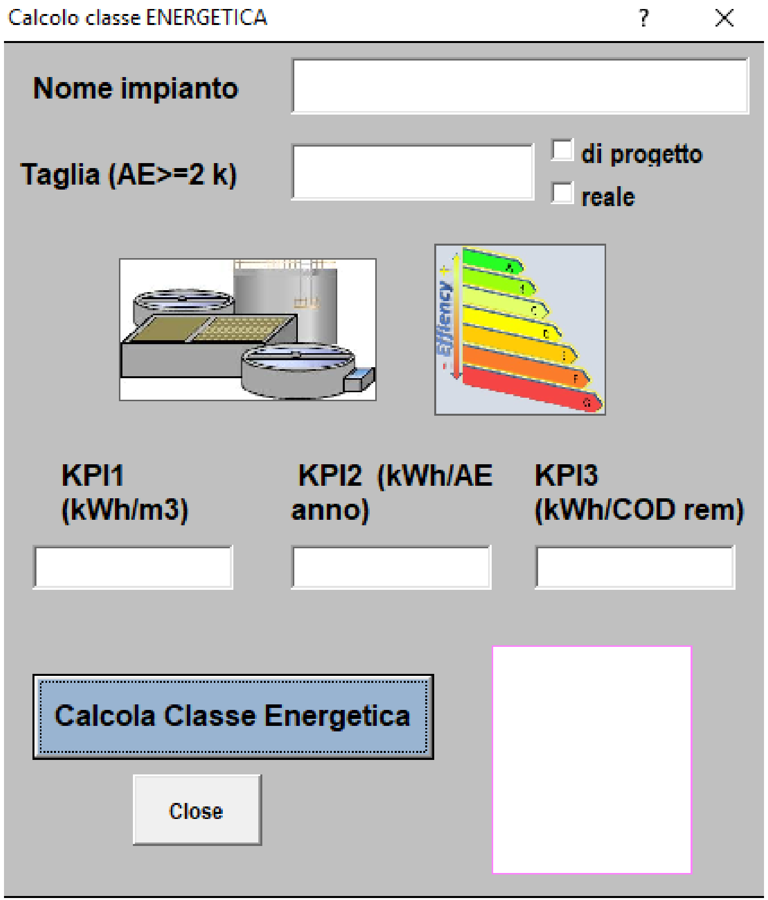
- The proposed methodology allows to frame the plants in accordance with the energy performance.
- The ID falling in the lower positions of the box-plot graph result to be less efficient in energy management.
- The overall picture shows the good energy performance of the $ID_{cs}03$ and, on the contrary, the low performance of the size class plants> 200K P.E. ($ID_{cs}01$ and $ID_{cs}02$).
- ***A more detailed analysis is needed for less performing plants in order to identify the specific existing critical issues and potential interventions.***

Work in progress (Preliminary version)

Implementation of a software tool in VBA to classify WWTPs on the basis of the energy performances and in accordance with the proposed methodology.

[Invitation to share data]

Questions?



Thank you for the attention

Contact email:
gianpaolo.sabia@enea.it