The efficiency of wastewater plants: enquiring and modelling the factors affecting the performance

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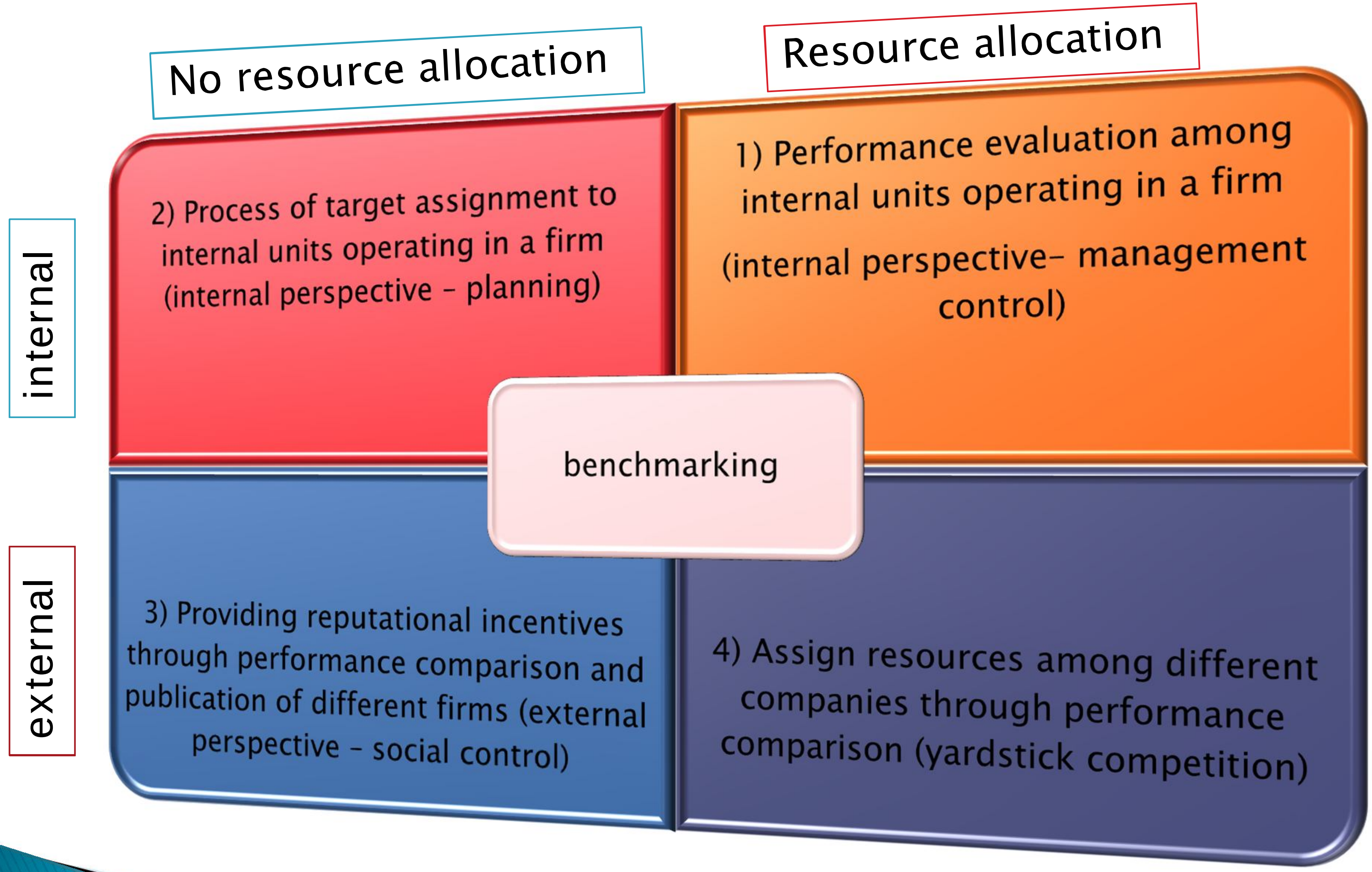
Identification of the objectives



The methods available

- Set of key performance indicators (*scorecarding*)
  - + performance can be observed from different perspectives;
  - - it is not easy to obtain an aggregated and single measure to make firms comparison.
- Parametric tecniques (regression)
  - + indentification of performance drivers;
  - - single perspective (cost or services).
- Non parametric tecniques (Data Envelopment Analysis)
  - + aggregation of many perspectives in a single score
  - - difficulties to disentangle the score obtained

Objectives and methods applied in some European countries

- Set of indicators to realize the so called *sunshine regulation* (Netherlands-VEWIN and Danmark-DANVA);

- Regression models to understand the determinants affecting utilities' performance and to identify value drivers (Danmark-regulatory benchmarking);

- Data Envelopment Analysis for efficiency estimation (Danmark-regulatory benchmarking).

The Danish regulatory model for wastewater services

Pipes	Pump stations	Rainwater pools	Sewage pools	Mini WWTPs	WWTPs	Sludge treatment	Customers
Kms of pipes in the zones: • Country + town, • City • Inner-city	Nr. of stations in the categories: • Household pumps • 0-10 l/t • 11-100 l/t • 101-600 l/t • 601-max l/t	Total number of pools	Total number of sewage pools	Total number of TP	Capacity (PE) loads in the category: •M •MB •MBNK •MBNKD (country) •MBNKD (town)	Tons of dry matter in the category: • A-sludge • B+C-sludge	Nr. of meters

The Danish regulatory model: the regression functions for cost estimations

Cost drivers	Cost equivalents
Pipes	$Y=4.279(X_1+X_2)+87.088(X_3+X_4)$
Pump stations	$Y=6{,}628X_1+13{,}891X_2+24{,}337X_3+102{,}864X_4+597X_5$
Rainwater pools	$Y=13{,}523X_1$
Sewage pools	$Y=19.74X_1$
Mini WWTPs	$Y=2{,}540X_1$
WWTP	$Y=1{,}581.92X_1^{0.67}+2{,}991.14X_2^{0.67}+3{,}113.49X_3^{0.67}+3{,}279.19X_4^{0.67}+3{,}891.82X_5^{0.67}+4{,}076.24X_6^{0.67}+373.65$
Sludge treatment	$Y=3{,}965.4X_1+4{,}747.7(X_2+X_3)$
Customers	$Y=120.8X_1$

Benchmarking of WWTPs. A case study in Tuscany

- **October 2014** – discussion of a benchmarking project with water local authority;
- **October 2014** –A tuscans water firms provides its interest to test a benchmarking model on its WWTPs;
- **November/December 2014** – definition of a grid of data, with the collaboration of a water firm and AIT staff;
- **Jenuary/March 2015** – data collection
- **April 2015** – statistical tests and data analysis
- **June 2015** – Data presentation

The grid of data – input and output variables

INPUT	OUTPUT
Cost of materials (reagents and other materials)	Kg removed of BOD5
Cost of Energy	Kg removed of COD
Staff cost	Kg removed N
Maintenance cost	Kg removed P
Depreciation and amortization	Kg sludge (wet matter)
Costs for sludge trasport and disposal	% dry matter obtained
	Kg other wastes
	Cubic meter of water treated
	% non complied controls with env. std.

The grid of data – Environmental and operating variables

Plant capacity	Person Equivalent
PE working capacity/PE theoric capacity	%
% diluition of wastewater inflow	%
% wastewater from non domestic customers	%
Year of building	
Type of sewerage system (S-separated; M-mixed)	S/M
Sludge treatment (YES/NO)	YES/NO
Type of plans (primary-1/secondary-2/terziary-3)	1/2/3
Type of secondary treatment (FA-active sludge; A-other)	FA/A
Type of aeration system (P-punctual; D-widespread)	P/D
Plant authorized with derogation	YES/NO
Av. concentration of BOD5 (inflow)	mg/l
Av. concentration of COD (inflow)	mg/l
Av. concentration of N (inflow)	mg/l
Av. concentration of P (inflow)	mg/l
% of sludge disposed in landfill	%
% of sludge given to composting plants	%
% of sludge given to agricolture	%
% of sludge given to incinerator plant	%
Distance between WWTP and sludge treatment plant	km

Statistical model – backward process

OLS model

y= total plant costs for 2014

x= output and operating and environmental variables

β = average amount by which y increases or decreases when the x increases

$$y = \sum_{i=1}^{n} \beta_i * x_i$$

- **Extended model**: all the 20 exhogenous variables collected were observed
- **Reduced model:** observes only the 9 statistically significant variables of the extended model

Results obtained

output

capacity

customers

process

Sludge diposal

Reduced model	R=0.9675
	ESTIMATORS
kg of N removed	positive**
kg of sludge removed	positive**
kg of other wastes removed	positive***
Plant capacity (PE)	negative***
% of wastewater from non domestic customers	positive*
Presence of a sludge treatment plant	(YES) positive***
Plant authorized to not comply with env. law	(YES) negative***
% of sludge provided to composting plant	negative***

1) Identification of *cost drivers*

+

Kg of removed pollutants;

% non domestic cutomers;

Presence of a sludge treatment plant

−

Scale economies;

Derogation;

% sludge disposed in composting plant

Evidences from prior studies

A number of publications have focused on analysing the managerial efficiency of water supply companies (e.g. Anwandter and Ozuna, 2007; Byrmes et al., 2008; Saal and Parker, 2009; Schaefer, 2010). However, the application of such tools in the field of wastewater treatment plants (WWTPs) has remained limited (but see Hernandez-Sancho et al. 2011; Hsiao et al., 2012).

Hernandez-Sancho et al., 2011: sample of 196 WWTPs located in the Valencia Region, 2003–2008. Efficiency was affected by the significant **economies of scale** and the type of technology in use. **Energy consumption** is a key factor towards improving the productivity of WWTPs;

Hernández-Sancho et al. (2011a): it applied a nonradial Data Envelopment Analysis (DEA) to a sample of Spanish WWTPs. Results showed that **plant size, quantity of eliminated organic matter, and bioreactor aeration type** are significant variables affecting energy efficiency of WWTPs.

Senante et al. (2014): it confirms that all inputs are affected **by economies of scale**. As expected from other empirical applications (Dogot et al. 2010; Zessner et al. 2010), the mean efficiency for all inputs was greater for WWTPs with **higher PE** than for smaller plants. Regarding individual scores, all of the plants indicated that **older plants are less efficient** than younger plants.

2) Target cost estimation

- Estimation of predicted value for each firms in order to assign target in terms of cost.

- A comparison between actual and target costs gives favorable (actual < target) or unfavorable variances (actual > target).

- **The weight of variance on actual costs** signals the importance of the measured efficiency/inefficiency

2) Target cost estimation

WWTPs	Target cost	Actual cost	Variance	Weight of variance
Dep 015	1,000,000	1,200,000	- 200,000	-16.67%
Dep 016	900,000	700,000	200,000	28.57%
Dep 017	650,000	658,000	- 8,000	-1.22%

Identyfing the inefficient plants and analysis of the main causes related to variances

3) A planning tool to project a plant

X are the characteristics of a WWTP, hypothesized before its construction; Y is the target operating cost referred to each projected plant

$$y = \sum_{i=1}^{n} \beta_i * x_i$$

Cost Driver		Estimators	Target cost
Capacity	100,000		
Kg N removed		*9.155474*	
kg P removed		*-4.208719*	
kg sludge removed		*0.0128879*	
kg other wastes removed		*0.656516*	
Capacity	100,000	*-4.390983*	
% wastewater non domestic customer	50%	*73277.24*	
Sludge treatment plant	yes	*196048.8*	
Derogation	no	*-56706.84*	
% sludge disposal in composting plants	10%	*-164072.4*	

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Cost drivers		Estimators	Target costs
Capacity	100,000		
Kg N removed	200,000	*9.155474*	
kg P removed	74,000	*-4.208719*	
kg sludge removed	3,500,000	*0.0128879*	
kg other wastes removed	250,000	*0.656516*	
Capacity	100,000	*-4.390983*	
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Cost drivers		Estimators	Target costs	
Potenzialità	100.000		€	1.506.068
kg rimossi n	200.000	*9.155474*	€	1.831.094
kg rimossi p	74.000	*-4.208719*	-€	311.445
kg fango	3.500.000	*0.0128879*	€	45.107
kg altri rifiuti	250.000	*0.656516*	€	164.129
potenzialità	100.000	*-4.390983*	-€	439.098
perc reflui da attività produttive	50%	*73277.24*	€	36.638
trattamento fanghi si 1 no 0	1	*196048.8*	€	196.048
impianto in deroga 1 si 0 no	0	*-56706.84*	€	-
perc smaltimento fanghi in compostaggio	10%	*-164072.4*	-€	16.407

Potentials and risk of a benchmarking tool for Tuscan water utilities

- **Progressive extension** of benchmarking process among the 7 water firms operating in Tuscany.
- **Blinded performance comparison** in the first stage, whose evidence would be shared only among water utilities
- Implementation of **sunshine regulation**, without any effect on resources allocations;
- **Improvements of the statistic model** choosing among alternatives methods (DEA, SFA ecc.).