Transient and Persistent Energy Efficiency in the Wastewater Sector based on Economic Foundations

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As the number of wastewater treatment plants (WWTPs) increases worldwide and the effluent quality requirements become more demanding, the issue of energy efficiency has been attracting increasing attention from an environmental and economic point of view. Recent approaches to estimating WWTP energy efficiency, based on e.g. Data Envelopment Analysis (DEA), have focused on controlling for exogenous variables (e.g. temperature, influent dilution, etc.) ignoring the possible presence of omitted (unobserved) variables. In effect, WWTPs may be characterized by operating under particularly heterogeneous environment, due to e.g. different topography of the service area which has a direct effect on the number of lift pumps and therefore on electric energy consumption. Variation in operating environment that manifests as variation in energy use, if not controlled for, may be misinterpreted as efficiency differences and can lead to poor root-cause diagnosis. Furthermore, since the level of efficiency can be decomposed in two parts, one persistent and one transient, for a correct low-efficiency diagnosis, distinguish between the two component seems important. Otherwise, water utilities may wrongly decide to invest in new equipment and infrastructure, while inefficiency arises from some application of wrong operational strategies due to e.g. error in management of sludge age and return sludge, too infrequent sampling or inadequate evaluation of monitoring data, or vice versa.

Using data from 183 Swiss WWTPs over the period 2001 to 2015, this research applies a novel approach of Stochastic Frontier Analysis (SFA) for energy demand modelling to estimate the comparative energy efficiency of a comprehensive set of WWTPs, as far as in known, for the first time. The objective of this paper is to investigate how overall inefficiency of WWTPs is decomposed into persistent and transient inefficiency and the importance of each of these components in the sector. Energy efficiency estimates obtained from three panel data models are compared in order to find out whether accounting for unobserved heterogeneity in the model significantly influences the results.

The proposed electricity demand specification controls for the price of energy, volume of wastewater treated, plant capacity, concentration of main pollutants removed from wastewater (e.g. COD, NH4 and NO3), temperature, type of secondary treatment and the presence of sludge dewatering in order to obtain a measure of energy efficiency. Overall, a fair degree of variation among plants is established in energy efficiency estimates, indicating that there is considerable room for improvement. The results illustrate that the efficiency scores are, as expected, sensitive to model specifications. Depending on the model employed, considering overall efficiency estimates, WWTPs could save on average as much as 20–60% of their electricity usage, being persistent energy inefficiency more severe than transient energy inefficiency. Consequently, the majority of inefficiency is not caused by operational technical problems but instead to recurring (over the years) identical problems. Thus, unless there is a structural change in the operation of individual plants such as a change in mechanical equipment, it is very unlikely that inefficiency will change. However, by employing

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a model able to decompose the time-persistent component of inefficiency into a time-invariant heterogeneity effect and a persistent inefficiency effect, we show that a large part of the persistent inefficiency is due to time-invariant unobserved heterogeneity suggesting that differences in topography may affect significantly efficiency at WWTP, hence its effect should be controlled for in order to obtain meaningful efficiency estimates.

Furthermore, it is shown that the level of energy efficiency of equipment influences the demand for energy. Consequently, technological innovation can induce a reduction of energy consumption provided that the equipment is used in an efficient way. Finally, the estimation of economies of output density and scale suggests that large energy savings can be achieved by directing higher volume of wastewater to the plant. On the one hand, it is confirmed that it would be convenient for WWTPs to operate at the maximum possible scale due to the presence of economy of scale. On the other hand, it is shown that economy of output density is even a bigger driver to reduce the unit consumption. Even if in general, design guidelines propose over-dimensioned WWTP designs in order to avoid malfunctions and non-compliance with effluent requirements, our results suggest that special attention should be given during WWTP designing phase in order reduce energy demand by avoiding extra and unnecessary reaction volumes.

Concluding, it is seen that, thanks to the possibility to take into account the presence of unobserved heterogeneity, to distinguish persistent from transient inefficiency and to take into account the statistical noise of data errors, the proposed approach, compared to previous research, is superior to deduce appropriate energy diagnosis in order to make inefficient WWTPs efficient. In light of the above findings, the methodology and results of this study can be of great interest for researchers, policy makers and plant operators in designing new WWTPs, developing optimal energy saving operational strategies and make informed decisions for improving energy efficiency of WWTPs.