COMPARATIVE ENERGY EFFICIENCY OF SWISS WASTEWATER TREATMENT PLANTS BASED ON ECONOMIC FOUNDATIONS

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Overview

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. Earlier approaches to measuring WWTP energy efficiency such as Data Envelopment Analysis (DEA) have recently focused on controlling for exogenous variables ignoring the possible presence of omitted (not observed) variables. This omission can lead to biased efficiency index. Moreover, since the level of efficiency can be decomposed in two parts, one persistent and one transient, based on such approaches, water utilities may decide to invest in new machines and infrastructure, when instead the origins of inefficiency come from a non-optimal use of some machines or vice versa.

The objective of this paper is to investigate how overall inefficiency of WWTPs is decomposed to persistent and transient inefficiency. This allows better evaluation of energy saving measures since both components convey different types of information. While persistent inefficiency reflects long-term structural problems due to, e.g., energy inefficient equipment used for wastewater treatment, transient inefficiency is associated with process operational practices or decisions that take place in the short term. Distinguish between persistent and transient inefficiency, while controlling for exogenous factors, is thus essential to deduce appropriate energy diagnosis and design useful energy efficiency strategies for WWTPs. This research applies a novel approach of Stochastic Frontier Analysis (SFA) for energy demand modelling to estimate the comparative energy efficiency of a comprehensive panel of WWTPs in Switzerland, as far as in known, for the first time.

Methods

We argue that the estimation of a measure of the efficient use of energy of WWTPs could be based on the estimation of a single conditional input demand frontier function, such as the demand function for energy (Filippini and Hunt 2015). This function indicates the minimum amount of energy that is necessary to produce a given level of energy services (i.e. the removal of pollutants from wastewater), given the WWTP's characteristics and other factors. The model used in this study is the SFA based on Kumhakar, Lien and Hardkar (2014). This model not only distinguishes between time-varying and time-invariant efficiency but also between efficiency persistent and the latent firm effect (unobserved heterogeneity). Therefore, the following aggregate WWTP input energy demand function is specified:

$$E_{it} = \alpha_0 + \alpha_P P_t + \alpha_{FLOW} FLOW_{it} + \alpha_{SIZE} SIZE_i + \alpha_{COD} COD_{it} + \alpha_{NH4} NH4_{it} + \alpha_{NO3} NO3_{it} + \alpha_T T_i + \alpha_{TECH} TECH_i + \alpha_{DEW} DEW_{it} + \mu_i + v_{it} + \eta_i + u_{it} \quad (1)$$

where E_{it} is the aggregate energy consumption (kWh/day), $FLOW_{it}$ is the wastewater flowrate (m^3/d), $SIZE_i$ is the design flowrate (m^3/d), COD_{it}, $NH4_{it}$ and $NO3_{it}$ are the main pollutants (mg/L) removed by the WWTP, P_t is the real price of energy (CHF/kWh), $TECH_i$ is the type of secondary treatment technology, T_{it} is the temperature (°C) and DEW_{it} is a dummy variable indicating wether or not the plant carry out the dewatering of sludge (an additional service of the WWTP). All variables except dummies are in logs. μ_i captures unobserved heterogeneity which is disentangled form persistent efficiency (η_i) whereas u_{it} and v_{it} are time-varying efficiency and standard error term respectively. α_0 and βs are unknown parameters. i and t stand for WWTP and time respectively. A multistep procedure is used to estimate model (1) by standard random-effects; using an unbalanced panel data for 201 Swiss WWTPs for the period of 2002 to 2016. Transient and persistent efficiency (TE and PE, respectively) are estimated from $TE = \exp(-\hat{u}_{it})$ and $PE = \exp(-\hat{\eta}_i)$, while the overall efficiency (OE) from $OE = TE \times PE$. Additionally, the model is extended to accommodate time-invariant factors determinants of persistent efficiency, such as the time trend effect on efficiency (year of plant construction[1], $YEAR_i$), i.e., from adoption of newer technologies. Such a model will also generate marginal effects of the determinants of efficiency, i.e., these marginal effects will give estimates of persistent efficiency changes due to change in *YEAR*.

Results

The estimation results of the frontier energy demand model show that the estimated coefficients have the expected signs and magnitudes, and are significant at the 1% level. The coefficients of the main pollutants removed by WWTPs suggest that both COD and NH_4 removal increase energy demand due to their requirement in aeration, while as NO_3 removal increases there is a tendency to use less energy, given that denitrification is not an energy consuming process but instead COD is used as a substrate, which in turn will no longer have to be oxidised.

The results for energy efficiency estimation suggest that both transient and persistent inefficiency are present, the latter being considerably more important in the sample. On average, TE is estimated to be 93%, PE 63% and OE 58% over the estimation period. The average (across WWTPs) of these efficiency measures is plotted over time in Figure 1 (left part). Regarding the marginal effects, we find that the effect of *YEAR* on the persistent efficiency function is negative for all observations. The convenience of renewing is highest for the oldest systems having the ability to eliminate up to 5% of their persistent inefficiency (Fig. 1, right part).

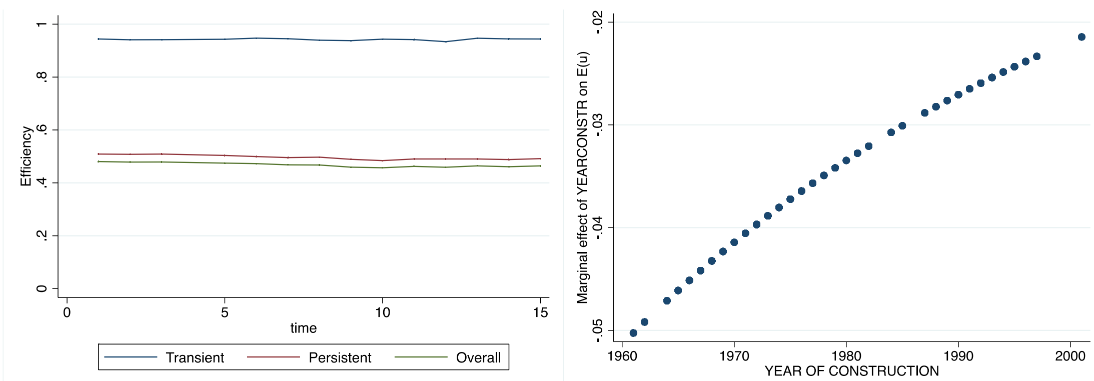

Figure 1. Efficiency over time (left); Marginal effects of *YEAR* on persistent inefficiency (right).

Conclusions

The findings show that the Swiss wastewater sector is characterized by the presence of both, transient as well as persistent, energy inefficiencies. The transient component, i.e., inefficiencies varying over time deriving from, e.g., wrong adaption of operational process strategies, is found to be quite low, indicating only marginal problems associated with the short-term management. On the other hand, the greater part of inefficiency is found to be persistent, i.e., long-term inefficiencies that do not vary over time, which reflects long-term structural problems due to, e.g., energy inefficient equipment used for wastewater treatment. The marginal effect of the year of construction is higher for older plants indicating that, if renovated, older systems have a higher margin to reduce their inefficiency in comparison with newer ones, which is reasonable. Hence, technological innovation can induce a reduction of energy consumption provided that the equipment are used in an efficient way.

References

Filippini, M. and Hunt, L.C., 2015. Measurement of energy efficiency based on economic foundations. Energy Economics, 52:S5-S16.

Kumbhakar, S.C., Lien, G. and Hardaker, J.B., 2014. Technical efficiency in competing panel data models: a study of Norwegian grain farming. Journal of Productivity Analysis, 41(2):321-337.

[1] Given that some of the WWTPs have received a major upgrade (i.e., all the main machineries have been replaced), in such a case *YEAR* refer to the year of last major upgrade.