Energy Efficiency Analysis of Water and Wastewater Utilities Based on the IBNET Database

Regional Centre for Energy Policy Research

Corvinus University of Budapest

Client:
The World Bank IBNET Program

Prepared by: REGIONAL CENTRE FOR ENERGY POLICY RESEARCH

Mailing address: 1093 Budapest, Fővám tér 8, Hungary
Office: 1092 Budapest, Közraktár utca 4-6, Room 707.
Phone: +36 1 482-7070 Fax: +36 1 482-7037
Email: rekk@uni-corvinus.hu

May 2010

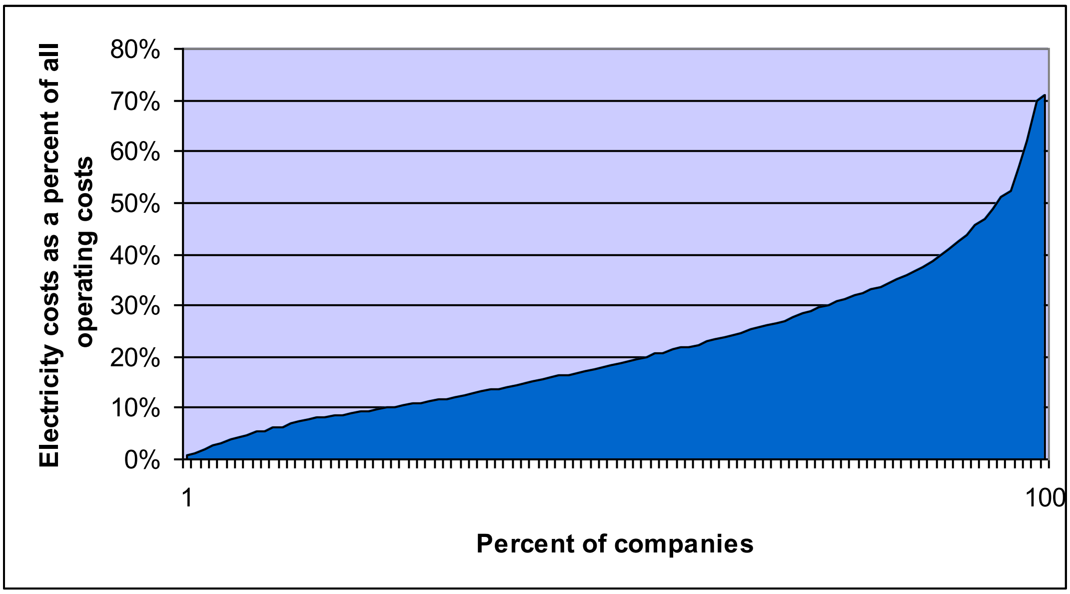
Authors:
Márta Bisztray *, András Kis *, Balázs Muraközy **, Gábor Ungvári *
* Regional Centre for Energy Policy Research, Water Economics Unit
** Institute of Economics, Hungarian Academy of Sciences

Table of Contents

I. INTRODUCTION

Electricity expenditures make up a large part of the operating costs of the water and wastewater sector. In case of the Central and Eastern European (CEE) and Commonwealth of Independent States (CIS)[1] utilities within the IBNET database[2], for half of the companies electricity costs comprise at least 18% of all operating costs, and for more than one-fifth of the companies electricity costs make up over 30% of all operating costs (Figure 1). Given the large share of these expenditures and the poor financial position of many of these companies, any reduction in electricity costs would be a well appreciated development.

Figure 1. Electricity costs as a percent of all operating costs, CEE and CIS water utilities



Source: IBNET database

Energy costs can be reduced in one of two ways:

1. Lower the unit cost of energy purchases/input.
2. Improve the energy efficiency of operations, i.e. consume less energy for the same amount of production.

There are multiple solutions to reduce the unit cost of electricity. In case of competitive electricity markets it makes sense to pay special attention to the procurement process in order

---

[1] Countries which were part of the Soviet Union were assigned to CIS, all other countries, including Turkey, are considered as CEE as part of this analysis.

to attain attractive rates. If the price of electricity changes within the day (as is the case for large consumers in most developed electricity markets), then water utilities can shift some of their consumption to hours with lower electricity tariffs through clever planning and active process control and automation – there is a large and growing body of experience in this field. Sometimes own generation of electricity is cheaper than purchase from the market. Production of heat and electricity from sewage sludge is a typical option, but there are some other, more exotic technologies as well. For example, according to Armar and da Silva Filho (2003), some of the water utilities in Brazil started to generate power from micro-hydro plants installed at water intake points. Since only economic investments were implemented, the overall energy costs were also reduced.

While the room for lower unit costs clearly exists - especially as electricity markets open up, multiple intra-day rates of electricity are introduced and the cost of renewable technologies drops -, the cost saving potential from improved energy efficiency is likely to be much higher. Therefore within the current document we will not address the unit costs of electricity purchases, but nevertheless would like to emphasize that this topic should be part of any reasonable water utility energy strategy. Hereafter we will focus our attention solely on the energy efficiency of water and wastewater utilities.

Improvements in energy efficiency are widely available, as suggested by field experience as well as research findings from all over the World. In the United States potential energy savings of 15-30 percent are "readily achievable" in many water and wastewater plants with substantial financial returns with payback periods of only a few months to a few years[3]. Given the condition of water and wastewater infrastructure in CEE and CIS we think that similar or higher improvements are feasible for *most* utilities, especially in lower income countries. Evidence of water supply retrofit schemes from Brazil, another economy in transition, supports these assumptions.

A straightforward way to see how energy efficient a company is compared to its peers is to compute one or more simple indicators. Such a benchmarking exercise is fairly easy to do, but one should be cautious of its results. It is well known that the value of energy efficiency indicators (e.g. kWh of energy used to deliver a cubic meter of drinking water) depends on external operating conditions as much as on company practices. A good value may be an indication of a well maintained, efficient technology – or a flat terrain with moderate need for

---

[2] www.ib-net.org

[3] http://www.epa.gov/waterinfrastructure/energyefficiency.htm

pumping. Sophisticated indicators can help to account for external conditions. Considering the difference in elevation for a given volume of transported water is a good way to incorporate such exogenous factors. The problem with these indicators is that they require specific detailed data, which is almost never readily available.

Alternatively, if there is a large database of water utility data, we can use statistical techniques to screen for the impact of operating conditions, assuming that the remaining difference between utility indicator values is up to differences in efficiency. Multiple variable statistical analysis of energy efficiency has been successfully applied in the water utility sector (e.g. Carlson (2007), Bisztray (2009a)). For a comprehensive review of studies focusing on productivity and efficiency see Abbott and Cohen (2009).

The IBNET database includes basic performance data of a large number of water utilities. Our purpose with the study is to see if it is possible to identify the role of operating conditions on the energy efficiency of utilities, using multiple variable statistical analysis. If we are successful then the ensuing results will have wide applicability, including the uses listed below:

- Utility managers often have an opinion on the magnitude of energy saving potential at their firm. The results from the analysis could confirm or disprove their views, and also help them set targets for reduction of energy use.
- Of a group of companies it becomes possible to select the ones with the largest room for energy efficiency improvement. This is valuable input for government policy, national and international aid programs, or banks/institutions providing financing to the sector.
- One of the worthwhile goals of benchmarking projects is exchange of best practices. The results of the described analysis will help to better select those companies which are likely to be good source of best practice information.

II. LITERATURE REVIEW

The chapter on literature review has been split in two. The first section provides a glimpse of the operating conditions that past studies have identified as material to the energy use of water and wastewater utilities. This information has been important in shaping our own statistical models and helping to judge the comprehensiveness of our work regarding the coverage of key variables. The second part of the literature review provides a brief overview of the measures that underperforming utilities can apply in order to lower their energy consumption.

II.1. The Role of Operating Conditions on Energy Use

We have studied a number of reports dealing with the internal and external factors shaping the energy use of water and wastewater utilities. In this section we review the key exogenous factors that have been found to have an impact on energy use. For each factor we will describe if the variable in question is also part of the IBNET database, and if not, if we have been able to approximate the missing variables from other sources and methods.

Larger utilities on average require less energy to pump a unit of water, in other words, economies of scale exist (Elliott et. al., (2003), Bisztray et. al. (2009b), Byrnes et. al. (2009) all confirmed this finding). Within the IBNET database size can be represented by multiple variables, including the volume of water sold and wastewater collected.

Both the source of raw water and the treatment applied to it can make substantial differences in energy use. Groundwater extraction from deep aquifers requires substantially more energy than extraction of surface water. Some of the advanced drinking water treatment technologies, such as ozone disinfection and membrane filtration are energy intensive (Elliott et. al., 2003). Bisztray et. al. (2009b) in their analysis assigned drinking water treatment technologies into one of two categories (“inexpensive” and “expensive”) based on the opinion of utility experts. Their analysis indicates that Hungarian utilities applying expensive technologies to treat at least 10% of their drinking water face on average 0.13 EUR/m^3 higher costs than the rest of the companies. How much of this exactly is due to higher electricity use has not been investigated, but utility experts confirmed that more expensive technologies are also more likely to be energy intensive. Since data on water bases and drinking water treatment technologies is not available within the IBNET database, this factor is not investigated in the present study.

Terrain is also a key factor in explaining energy use. Hungarian utilities operating in hilly areas, categorized as a service area with larger variation in altitude above sea level, use on average 0.65 kWh/m^3 more energy for water and 0.2-0.6 kWh/m^3 more for wastewater than companies from flat areas (Bisztray et. al. 2009b). The IBNET project does not collect data on the terrain, but knowing the location of the main cities of each utility, it has been possible to generate a proxy for terrain (Chapter III.3).

The AWWA Research Foundation undertook a project to develop energy benchmarking indicators for water and wastewater utilities (Carlson and Walburger, 2007). Since the researchers did not have to work from an existing database, but developed their own survey instruments, it became possible to test the role of a wide spectrum of previously untested variables. Data from 266 wastewater treatment plants and 125 water utilities was statistically analysed. The analysis showed the value of process level benchmarking, i.e. creating separate models for drinking water treatment, drinking water delivery, sewage collection and sewage treatment, and possibly also for sub-processes, using detailed data tailored especially for the process in question. Landon (2009) and Gay Alanis (2009) also emphasize the important contribution that process level benchmarking can make.

Listed below are the key variables that according to the results of Carlson and Walburger (2007) are important drivers of energy efficiency at the process level. The majority of the described data is not available within the IBNET database, therefore process level analysis as part of the current project is not feasible.

- For drinking water delivery total volume, pumping horsepower, the length of distribution mains, network loss and change in elevation through the network played a key role. Of these variables, volume, the length of the distribution mains, and network loss are available in the IBNET database and can therefore be tested in our analysis.
- For drinking water treatment specific technologies – such as oxidation, iron removal, direct filtration and ozone treatment – proved to be important determinants of energy use. Drinking water technologies are not part of the IBNET survey.
- For sewage collection, besides volume, the pumping horsepower and the number of pumps proved to be important input variables. Pumping data is not collected as part of the IBNET exercise.

- For wastewater treatment the following variables substantially impacted energy use: volume of inflowing wastewater, BOD removal, nutrient removal, capacity utilization, application of trickle filtration. Of these, only volume of wastewater is part of IBNET.
- In case utilities are scattered through a large geographical area, weather may also influence energy use, through differing needs for heating or cooling. Weather data is not part of the IBNET database and while such information could be assembled, we decided to skip it as there are a number of more important drivers of energy use which are already part of our analysis.

II.2. Potential Measures to Improve Energy Efficiency

Once an analysis identifies the utilities which are likely to have the largest room for energy efficiency improvements, the question that comes to mind is “what can be done to actually lower energy use?”. While answering this question is not among the original goals of our current research, we would like to provide a brief review of the options often cited in literature and guide the reader to some of the valuable reports dealing with this topic.

Before we review the measures, let us provide two general comments:

- Often utility managers are aware of many of their energy saving options, but a full review is best attained through energy audits involving independent experts with experience in water and wastewater utility technologies. Learning from best performing water companies can nicely supplement energy audits.
- Not all energy saving measures are cost-effective to the same extent. A lot of investments will have an attractive pay-back period, while others will take a long time to become self-financing. Managers of utilities with scarce resources are not likely to pursue investments with poor financial returns, but nevertheless, it is good to remember that energy saving investments - or any investments aimed at cost savings -, should ideally be done in an order based on some measure of financial return, like internal rate of return. Multi-purpose investments, which besides energy efficiency also target e.g. more secure supply or better quality drinking water, should obviously be decided on using multiple criteria, financial returns being one of them.

Leakage Reduction

According to Raucher, et. al. (2008) annually an estimated 5-10 TWh of electricity is used to pump water which is eventually lost from the networks in the United States. Some of the CEE utilities face drinking water network loss ratios well above 40%. Cutting leakage will reduce the amount of pumped water and therefore the energy need for pumping. Modern technologies can identify the network sections with the biggest savings potential, network remediation should obviously start at these locations.

Improved Pumping

Ijjaz-Vasquez (2005) describes that in the countries of the former Soviet Union about 95% of the energy use of water utilities is attributed to pumping operations. This is the result of large network losses as well as inefficient pumping facilities, due to old age, poor design and improper size. Pumps are often oversized, especially in places where water consumption fell due to increased prices and changes in the economy, and therefore are less efficient when pumping lower volumes of water. Replacing old pumps with more energy efficient devices not only saves energy, but in many cases it will also save maintenance costs and ensure more reliable service. Sometimes it is enough to refurbish existing pumps. These investments often have a short repayment period. As an example, Armar and da Silva Filho (2003) cites two case studies in Brazil in which it was determined that 20 and 30 percent of pumps needed some sort of intervention, resulting in reduced energy use of 5-6 percent. In case pumps are replaced, long-term forecasting of water consumption can aid in selecting energy efficient pumping technology (Jentgen *et. al.*, 2007). The USEPA (2008) recommends that variable frequency driver pumps are considered, as these can adjust to flow volumes and therefore save energy during low volume periods.

Sophisticated Control Systems

There are many novel processes taking advantage of recent technical developments in the field of information technology, engineering, biotechnology and others, which contribute to enhanced operations and energy savings at water and wastewater utilities. While we mention some of these here, our list is far from complete, but should be sufficient to illustrate the wide range of new applications.

Remote sensing and controlling of water flows and pressure helps to avoid excess network pressure, contributing to energy savings in two ways. On the one hand, lower pressure requires less pumping, and on the other, lower pressure results in less leaked water, which in turn also requires less pumping. Intraday forecasting of water consumption and related water flows can be useful in optimizing operation, by utilizing higher efficiency pumps over lower efficiency pumps (Jentgen *et. al.*, 2007). Haecky and Perco (2009) report that replacement and modernization of the aeration system of a wastewater treatment plant in Granollers, Spain resulted in energy savings of 30% for the technology, which is the main energy user within the plant.

III. THE DATA USED

III.1. IBNET Data

The CEE and CIS sections of the IBNET database were used for the analysis. The database was cleaned in two steps:

First the whole database was checked for consistency, regardless of whether a specific variable would then be used as part of the current energy efficiency analysis. Raw data were scrutinized for errors, and erroneous data was corrected when feasible, or labelled as missing otherwise. Details about this process are provided in the Annex.

Next, the database was further cleaned specifically to satisfy the data need of the econometric analysis of the present project. Details of this exercise are provided below.

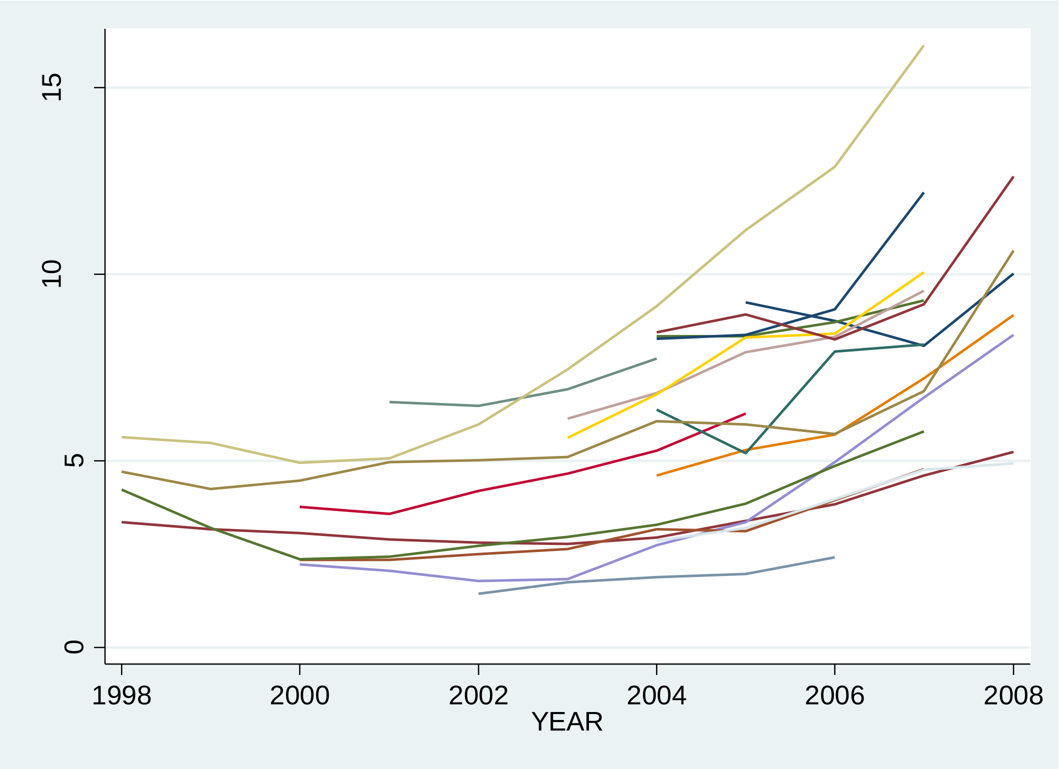
Our main goal with data cleaning was to delete firms where reported data may be distorted. Also, we tried to restrict the sample to possibly similar firms to estimate a ‘reasonable practice’, if not a ‘best practice’ electricity use function – we wanted to estimate the technological relationships for the average firm in the region. While it is possible to predict electricity consumption for firms outside the ‘reasonable practice’ sample, firms far away from the average technology should not modify the estimated relationships.

We dropped all firms where data about electricity consumption was missing because electricity cost was 0 or there was no data on electricity prices. Unfortunately, a large number of firms did not report electricity consumption in the IBNET database. In Belarus, Tajikistan and Uzbekistan none of the firms had electricity consumption data due to difficulties accessing good quality electricity price data from these countries, while a large share of observations are lost in Albania, Bosnia and Herzegovina, the Kyrgyz Republic and Slovakia. Altogether more than 100 firms are lost because of missing electricity use data.

We dropped firms which were involved in other possibly energy intensive activities like construction and transport, as it is impossible to estimate the amount of electricity consumed by these other activities. Theoretically these activities are excluded from the reported electricity cost, but we wanted to be on the safe side, especially, as there were only less than 100 firms dropped.

We dropped all years before 1998, as the data on electricity prices was unreliable before this. Even in 1998 and 1999, electricity prices are declining in USD terms, but this decline does not seem to be very important from the perspective of the analysis. Country-level electricity data is shown in Figure 2.

Figure 2. Non-residential electricity prices, including taxes and excluding VAT, annual average values computed from quarterly figures, USD cent/kWh



From our main estimation sample we dropped firms which were not involved in both water and wastewater services. Firms involved in only one of these activities are few, thus it is not easy to estimate a production function for them with any precision. We also dropped firms where the water production exceeded wastewater collection by a factor of 5 and vice versa. We, however, also estimated a flexible form relationship on the pooled sample of firms providing either service to be able to predict the electricity use for all firms.

We also dropped outliers with respect to energy efficiency. For this we used a simple rule of thumb: we calculated *relative electricity use* as electricity (in kWh) over the sum of water and wastewater (in 1000 m^3). We dropped firms for which this figure was below 50 or above 5000.

Table 1 shows how the cleaning procedure narrowed the sample step-by-step.

Table 1 Number of observations after cleaning

	Original sample	Observations from 1998	Observations with data on eletricity consumption	After dropping firms with other activities	After dropping outliers	Both water and wastewater
Albania	204	204	143	143	113	32
Armenia	34	31	31	31	29	29
Belarus	85	85	0	0	0	0
Bosnia and Herzegovina	81	81	25	25	25	20
Bulgaria	100	100	78	78	76	64
Croatia	105	105	70	70	70	38
Czech Republic	120	120	84	84	83	83
Georgia	219	219	182	182	140	103
Hungary	289	223	201	201	201	172
Kazakhstan	131	131	98	98	98	96
Kyrgyz Republic	81	81	39	39	33	25
Macedonia	61	61	52	15	15	3
Moldova	536	454	435	435	389	206
Poland	180	180	173	118	118	118
Romania	208	208	194	194	122	122
Russia	1027	939	397	397	391	381
Slovakia	24	24	12	12	12	12
Tajikistan	45	45	0	0	0	0
Turkey	100	100	70	70	68	21
Ukraine	468	407	394	394	312	174
Uzbekistan	25	24	0	0	0	0
Total	4123	3822	2678	2586	2295	1699

Table 2 shows how observations are distributed over time in the final sample (including firms which provide either water, wastewater or both services). Few countries reported in 1998 and 1999, and some countries did not report in 2008. We have data on all countries with the exception of Croatia in 2005, so we report comparative tables for this year (and 2004 for Croatia).

Table 2 The number of observations in the final sample by year

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	Total
Albania	0	0	0	0	0	0	0	20	4	46	43	113
Armenia	1	1	1	1	1	2	2	5	5	5	5	29
Bosnia and Herzegovina	0	0	0	0	0	0	1	6	12	6	0	25
Bulgaria	0	0	0	0	0	0	2	18	19	19	18	76
Croatia	0	0	0	18	17	17	18	0	0	0	0	70
Czech Republic	0	0	14	14	16	16	16	7	0	0	0	83
Georgia	0	0	18	18	19	19	19	17	10	10	10	140
Hungary	18	18	20	21	21	21	22	22	19	19	0	201
Kazakhstan	0	0	7	9	12	13	16	18	0	23	0	98
Kyrgyz Republic	0	0	0	0	6	7	7	7	6	0	0	33
Macedonia	0	0	0	0	0	0	3	4	4	4	0	15
Moldova	35	34	36	32	29	37	39	36	36	36	39	389
Poland	0	0	0	0	0	23	23	24	24	24	0	118
Romania	0	0	0	0	0	23	24	25	25	25	0	122
Russia	0	0	0	0	0	0	77	80	78	77	79	391
Slovakia	0	0	0	0	0	0	2	2	4	4	0	12
Turkey	0	0	0	0	0	0	14	15	15	18	6	68
Ukraine	39	39	58	59	23	23	23	16	16	16	0	312
Total	93	92	154	172	144	201	308	322	277	332	200	2295

III.2. Electricity Consumption

The IBNET survey collects data on electrical energy costs, but not on energy consumption. Electricity consumption was estimated by dividing the energy cost with the commercial price of energy. Data on energy prices was obtained either from the Energy Regulators Regional Association (ERRA) database, or the Eurostat Industrial Electricity Price database. For Belarus, Tajikistan and Uzbekistan we did not have a chance to get hold of good quality electricity price data therefore these countries were omitted from the analysis. Electricity prices were checked both across countries and years, to ensure that the database as a whole is consistent.

We believe that the generated dataset for electricity use is of good quality, but we are also well aware that further improvements could be made. To put our data into context, below we list some of the additional improvements – beyond the scope of the current analysis - that could lead to an even better database of electricity use:

- In some wastewater treatment facilities the sewage sludge is anaerobically digested and the resulting biogas is combusted to produce energy. This energy is in most cases used within the facility, satisfying part or all of the energy needs of the sewage treatment plant, and sometimes there is a surplus which is sold to the electricity grid. Biogas generated electricity used within the water and wastewater utility reduces the amount that needs to be purchased from the grid, therefore ideally this amount should be added to the purchased quantity of electricity. The energy use adjusted this way may in some cases be 10-15 percent higher than reported energy purchases. Power generation from biogas is a relatively new technology in the region, with a low rate of penetration therefore the results of our analysis are not likely to be materially affected by not accounting for it.

- Results of the analysis could probably be notably improved if electricity use was possible to estimate separately for the water and wastewater services. While we did not have a chance to do so, we applied econometric models which make an attempt to separate the impacts of the two services on total energy use. As it is clear from the literature review in Chapter II.1, analyzing process level energy use would make results even more accurate.
- If drinking water is purchased from an external source, less energy will be required on the part of the utility since the purchased water has already been extracted and treated. Likewise, bulk drinking water sold will carry an intrinsic energy content with it. Having data for the bulk drinking water sales it has been possible to separate the latter impact, but not the former one. Therefore companies buying a large share of their delivered drinking water from other utilities are likely to exhibit better energy efficiency than their true conditions.
- Ideally, all utility energy use should be converted to source energy use - with the possible exception of transport fuel -, as there is some variation of energy inputs among utilities. This issue was not possible to address within the current piece of research, lacking data on other energy uses, but we assumed that the overwhelming majority of energy use at the water utilities of the region is electricity.

III.3. Terrain

As our earlier analysis (Bisztray et. al., 2009b) of water and wastewater utilities in Hungary indicates, differences in topology among utilities drive some of the difference between the unit costs of operation and also some of the difference between the unit electricity use of water and wastewater services at different companies. In this research terrain was numerically represented by the standard deviation of the altitude above sea level of each settlement within the service area. We also aimed to grasp the geographical differences of the IBNET sample of waterworks to test the relation between terrain and energy use. As we lacked information on the spatial attributes of the service areas of the utilities within the IBNET database, we employed two methods to get a proxy for topology.

The first approach approximates terrain with the altitude above sea level of the main settlement of the service area. Essentially, we assumed that plain areas are more common at lower altitudes, while higher values indicate a mountainous environment with bigger altitude differences inside the service area.

With the second approach we generated a variable which measures the differences in altitude among eight points of the service area. A specific distance, determined by the estimated size of the service area based on the number of settlements, people served and population density[4], was measured from the center of the main city to eight directions (North, North-East, East etc.) and the altitude above sea level for these eight points was determined. Since population density was not computable for towns with less than 100,000 inhabitants, for these settlements an average value was used based on randomly available population density data from a number of locations.

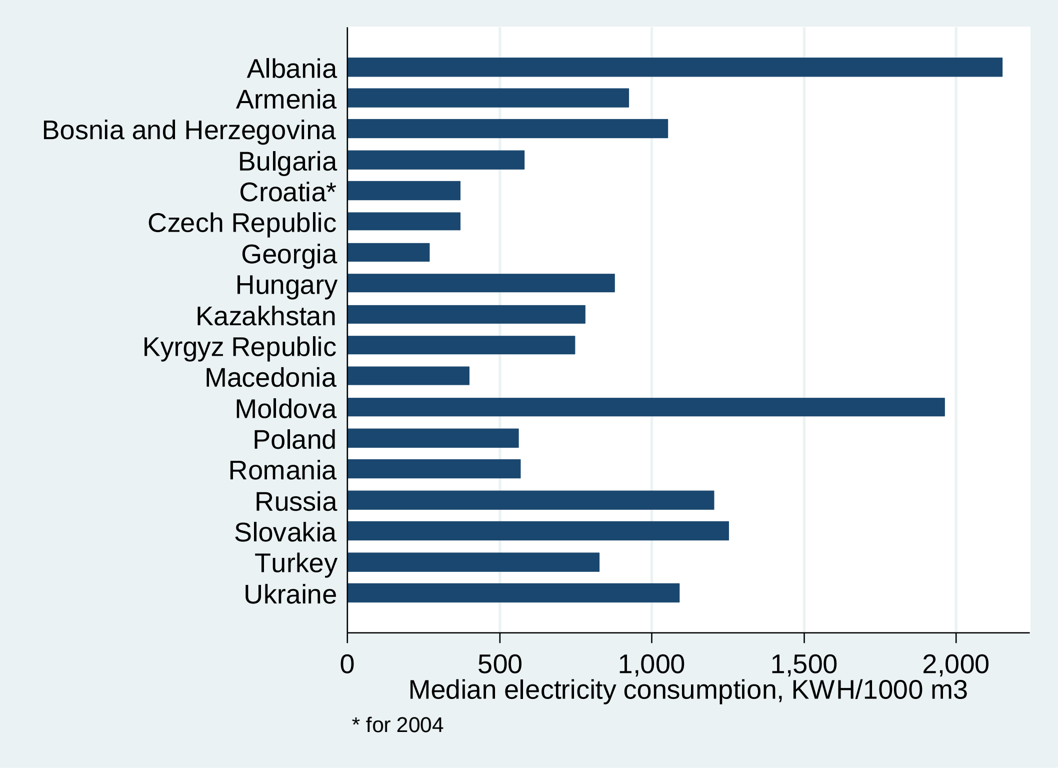
---

[4] http://unstats.un.org/unsd/demographic/products/dyb/dyb2007/Table08.xls

IV. DESCRIPTIVE STATISTICS

In this section we report descriptive results using a proxy for energy efficiency – assuming simply that each cubic meter of water or wastewater requires the same amount of electricity.[5] This variable is calculated as electricity use/(water sold + wastewater quantity); its unit of measurement is kWh/1000 m^3. Figure 3 shows the average of this efficiency measure for different countries in 2005.

Figure 3. Median electricity consumption in kWh/1000 m^3



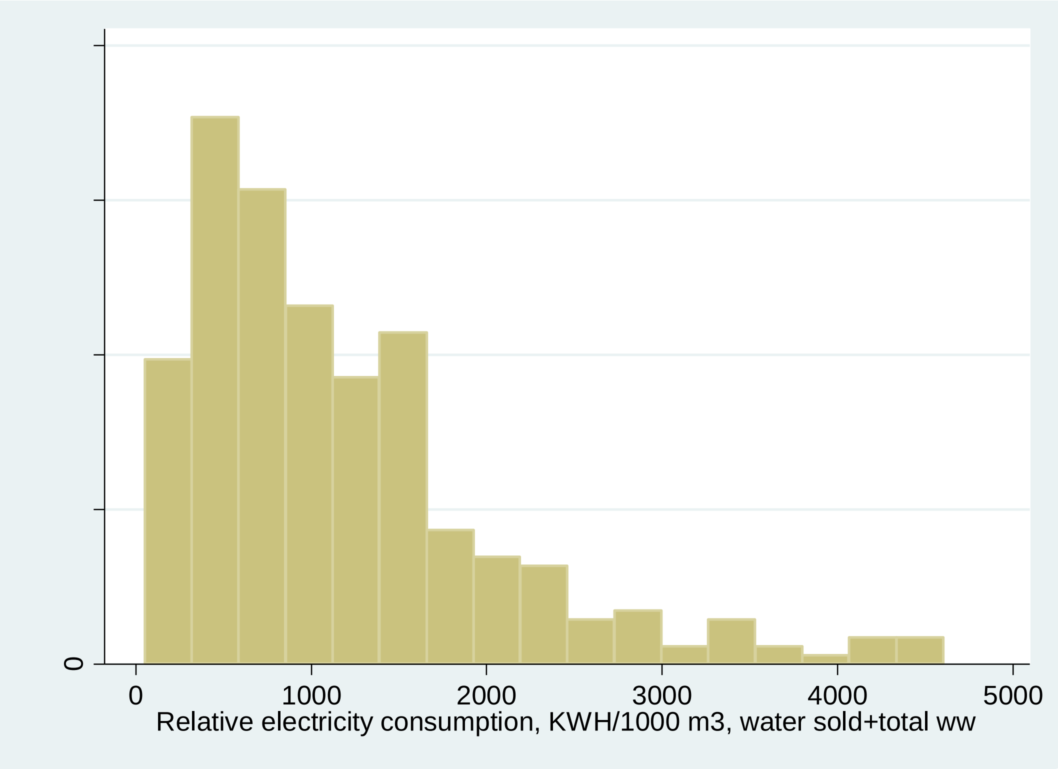
This graph shows large differences across countries, with larger efficiency on average in higher income countries. Albania and Moldova are strong outliers with exceptional negative performance according to this measure, followed by Slovakia (note that we have only two observations for Slovakia in 2005), Russia and Bosnia-Herzegovina. At the other end of the scale, Georgia, Croatia and the Czech Republic are the most efficient by this simple calculation.

---

[5] From other sources we are aware that this is rarely the case, but did not want to use an arbitrarily picked ratio especially as the difference among the countries of the region is likely to be substantial.

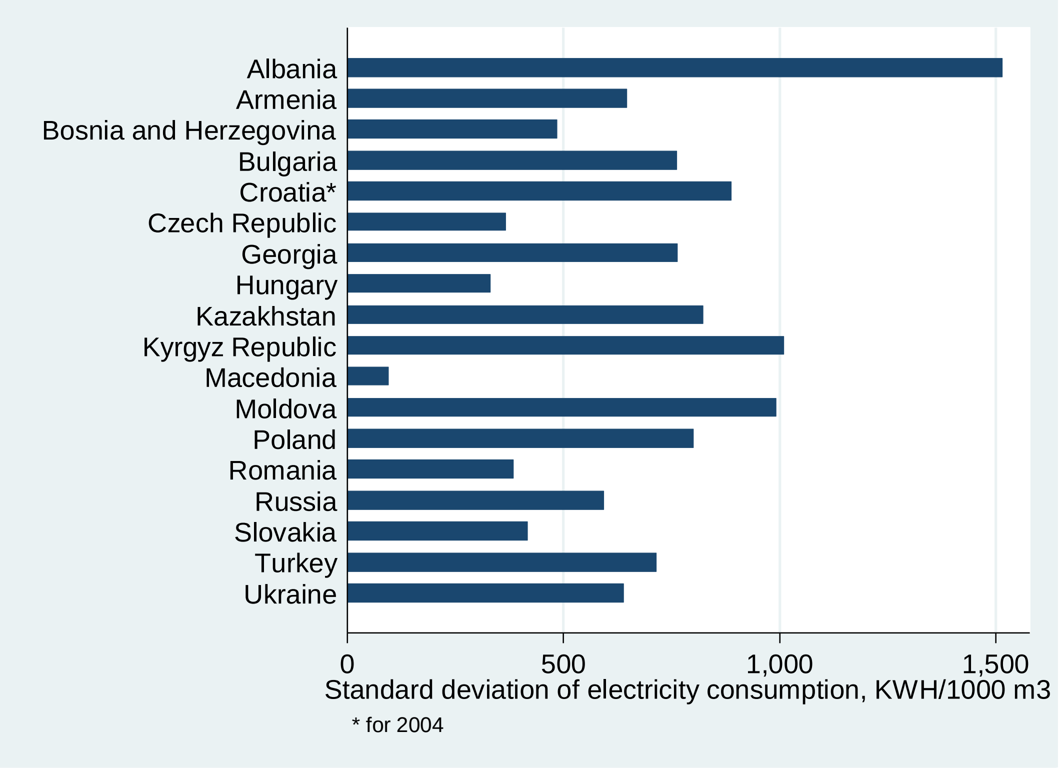
Second, we report the histogram of the proxy for electricity efficiency in 2005 in Figure 4, which suggests that there are large differences in terms of energy efficiency in the CEE and CIS region.

Figure 4. Histogram of electricity efficiency



The next question is whether efficiency and technology is determined by country level variables, or there is important within-country dispersion. To shed some light on this question, we calculated the standard deviation for this measure for each country, which we report in Figure 5.

Figure 5. Standard deviations of energy consumption, kWh/1000 m^3



The graph reveals that there are large deviations across utilities within countries. On average, these standard deviations are large compared to the median values: for the typical country, the median is about 800 kWh/m^3, while the standard deviation is between 300 and 500 kWh/m^3. The largest within-country variation is reported in Albania, but in general, within-country standard deviation tends to be larger in CIS and Southern European countries than in the rest of CEE. These numbers suggests that electricity use is not only determined by country-level conditions but individual service providers may improve their performance to a significant degree if they adopt the best practice in their respective countries, especially in CIS and Southern European countries.

V. REGRESSION ANALYSIS

V.1. Methodology

Next, we apply regression analysis to estimate the determinants of energy efficiency.

Our model follows a cost function approach. In this approach we assume that the electricity need of the firm is determined by the quantity of water and wastewater provided by the firm:

(1) $$Electricity_{it} = Efficiency_{it} * Water_{it}{}^{\beta_1} * Wastewater_{it}{}^{\beta_2} * e^{u_{it}}$$

Where *i* denotes firms, *t* denotes the time period, $Electricity_{it}$ is the quantity of electricity consumed by the firm, $Water_{it}$ is the water provided by the firm, $Wastewater_{it}$ is wastewater collected by the firm, β_1 and β_2 are the elasticity of electricity use with respect to water and wastewater provision, respectively. If $\beta_1 + \beta_2 < 1$, then increasing returns to scale are present: doubling both water and wastewater quantity requires less than doubling the electricity use. $Efficiency_{it}$ shows the energy efficiency of the firm: the smaller this number, the less electricity the firm consumes per unit of water and wastewater provided. u_{it} denotes the error term of the regression.[6]

Note that we implicitly assume that technology is similar for all firms in the sample, in the sense that the elasticities, β_1 and β_2 in it are the same for all firms, and firms only differ in their efficiency. As the empirical analysis shows, country-by-country estimation suggests that this is the case.

When estimating, we take the natural logarithm of both sides of the equation:

(2) $$\ln Electricity_{it} = \ln Efficiency_{it} + \beta_1 \ln Water_{it} + \beta_2 \ln Wastewater_{it} + u_{it}$$

In the following we assume that the energy efficiency term is a function of different variables, e.g. nature of service area, population density, country dummies. Thus when we are interested in the effect of population density on efficiency, we assume that

---

[6] We experimented with other functional forms, but this proved to be the most stable.

$\ln Efficiency_{it} = \gamma_0 + \gamma_1 Density_{it} + v_{it}$: efficiency is a (stochastic) function of population density. By substituting this to (1), we estimate:

$$(3) \qquad \ln Electricity_{it} = \gamma_0 + \gamma_1 Density_{it} + \beta_1 \ln Water_{it} + \beta_2 \ln Wastewater_{it} + u_{it} + v_{it}$$

Here γ_1 shows the relationship between population density and energy efficiency. A negative sign of the parameter reflects that energy efficiency is larger in more dense cities. Its point estimate shows that a one-unit change in density is associated with γ_1 percent reduction in energy use when one holds water and wastewater consumption constant. When other variables are included, they can be interpreted in a similar way. We also include a set of country dummies which allows systematic differences in efficiency between countries.

We interpret (1) as a technological relationship: technology is predetermined and water and wastewater demand are exogenous for the firm. Estimation by Ordinary Least Squares (OLS) is unbiased and consistent unless the unobserved part of efficiency (v_{it}) is correlated with the explanatory variables. This may happen if, for example, in large cities water utilities are more frequently modernized, and in such a case density may be correlated with the error term. The easiest way to check whether this is the case is to check whether coefficient estimates are robust for changing the sample.

V.2. Results

In our baseline specification the dependent variable is the natural log of electricity consumption by the firm expressed in kWh. The two output measures are ln water sold (in million m^3) and ln wastewater collected (in million m^3). Ln water network length (in kilometers) represents the electricity required by the network, a kind of fixed cost. The variables related to electricity efficiency are ln network loss (also in million m^3), ln population density and area type (urban, rural or both). In these specifications a full set of country dummies and a time trend[7] is always included.

---

[7] Including a set of year dummies does not seem to improve the estimates. It is not surprising, as we have no nominal variables in our specifications.

Summary statistics and correlations of these variables are reported in Table 3. Not surprisingly, inputs and electricity use are strongly correlated with each other. Network loss is also strongly related to these variables, but this correlation is somewhat weaker. Quantities are larger in cities, and they are also increasing in time.

Table 3 Summary statistics

Summary statistics							
Variable	Obs	Mean	Std. Dev.	Min	Max		
ln electricity usage	2295	8.733506	2.226108	0.6234345	14.34729		
ln water sold	2295	1.3762	2.186282	-4.60517	7.387877		
ln length of network	2225	5.526153	1.508446	1.360977	9.330787		
ln wastewater	2295	1.482443	2.060896	-5.809143	7.580092		
ln network loss	2205	0.600476	2.242904	-6.475969	5.753397		
ln population density	2272	7.382397	0.7118666	5.589431	10.67681		
Year	2295	2004.014	2.80541	1998	2008		
Correlations							
	ln electricity usage	ln network lenght	ln water sold	ln wastewater	ln network loss	ln population density	Year
ln electricity usage	1						
ln water sold	0.9273	1					
ln length of network	0.8182	0.8754	1				
ln wastewater	0.8188	0.8453	0.7107	1			
ln network loss	0.8509	0.8954	0.8452	0.7424	1		
ln population density	0.6013	0.6208	0.4458	0.5719	0.5821	1	
Year	0.1698	0.1697	0.1818	0.0561	0.2765	0.2073	1

When estimating, we do not include very large firms, consuming more than 20,000 MWh/year in the sample, because they can affect the coefficients strongly. This, however, does not mean that we cannot predict their energy consumption from the model.

Heteroskedasticity tests suggest that error variance is an increasing function of water use. Because of this we use robust standard errors for regressions within countries and country-level clustered standard errors when estimating on the pooled sample.

To utilize the panel structure of the data, we estimate our models with a random effects panel model. This makes the estimation and the standard errors more reliable. We also estimated by OLS, which led to similar results. Because of the panel structure we report three measures for explanatory power: within R-squared shows the percentage of *within-firm* variation explained by the variables, between R-squared characterizes explanatory power of *across-firm* differences, and overall R-squared shows the percent of variation explained from the *overall variation*.

First, to see the robustness of the regression, we estimate it separately for some countries with enough observations. We report our results in Table 4.

Table 4 Baseline results by country, estimated by random effects

	(1) Hungary	(2) Hungary	(3) Poland	(4) Poland	(5) Czech R.	(6) Czech R.	(7) Russia	(8) Russia	(9) Romania	(10) Romania	(11) Ukraine	(12) Ukraine
ln water sold	0.714***	0.389***	0.709***	0.497***	0.483***	0.252	0.449***	0.152	0.274	0.037	0.519***	0.286**
	(0.086)	(0.128)	(0.123)	(0.107)	(0.148)	(0.160)	(0.131)	(0.247)	(0.167)	(0.311)	(0.134)	(0.137)
ln network length	0.126	0.135*	0.048	0.042	0.318	0.244	0.532***	0.449***	0.607***	0.532**	0.630***	0.610***
	(0.083)	(0.072)	(0.082)	(0.081)	(0.220)	(0.226)	(0.172)	(0.151)	(0.187)	(0.253)	(0.201)	(0.201)
ln wastewater		0.326***		0.291*		0.214		0.335*		0.316		0.144**
		(0.092)		(0.150)		(0.144)		(0.176)		(0.221)		(0.065)
ln network loss		0.054		0.058		-0.003		0.023		0.008		0.043
		(0.046)		(0.063)		(0.075)		(0.049)		(0.038)		(0.047)
ln population density		0.728**		-0.062		1.492*		-0.058		0.013		0.136
		(0.335)		(0.251)		(0.841)		(0.199)		(0.144)		(0.158)
Rural		0.000		1.576		0.000		0.000		0.000		0.000
		(0.000)		(1.035)		(0.000)		(0.000)		(0.000)		(0.000)
Rural and urban		-0.083***		0.239***		0.633		0.091		-0.098		-0.528
		(0.028)		(0.085)		(0.389)		(0.065)		(0.188)		(0.364)
YEAR	-0.009***	-0.008***	0.008	0.004	0.011	0.013	-0.035**	-0.058***	0.045*	0.046	-0.016*	-0.022**
	(0.003)	(0.003)	(0.007)	(0.006)	(0.010)	(0.011)	(0.014)	(0.022)	(0.027)	(0.035)	(0.009)	(0.009)
Constant	25.819***	18.546***	-8.271	-1.005	-16.158	-31.113*	76.352***	123.340***	-86.025	-86.281	35.996**	49.220***
	(6.444)	(7.028)	(14.755)	(12.407)	(20.041)	(18.756)	(27.373)	(44.713)	(54.729)	(70.398)	(17.230)	(17.052)
Observations	172	172	118	118	83	83	369	369	122	99	174	172
Number of firms	27	27	24	24	16	16	81	81	28	25	37	36
Within R-sq	0.171	0.399	0.115	0.325	0.0339	0.0784	0.0619	0.0761	0.199	0.171	0.226	0.354
Between R-sq	0.908	0.903	0.916	0.956	0.815	0.823	0.848	0.855	0.572	0.619	0.901	0.901
Overall R-sq	0.895	0.868	0.920	0.949	0.806	0.816	0.778	0.786	0.528	0.562	0.896	0.895

First, it is reassuring that the coefficients of outputs are similar across countries, suggesting that our cost function in (1) may characterize well the data at hand. The estimated coefficients consequently show that water quantity drives electricity consumption and wastewater quantity matters less. The sum of the two coefficients is significantly smaller than 1 for all countries, showing strongly increasing returns to scale. Network length is significant in Russia, Romania and Ukraine. The other variables, on the other hand, do not show strong patterns across countries, which may be a consequence of the relatively small sample size or the large extent of technological heterogeneity.

The next issue is to estimate the baseline equation for a pooled sample of firms in different countries. We show results separately for Visegrad countries (Czech Republic, Hungary, Poland, Slovakia), CEE countries and CIS countries in Table 5. The regression is estimated only for firms producing both water and wastewater, and includes a full set of country dummies.

Table 5 Pooled estimation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	V-4	V-4	CEE	CEE	CIS	CIS	all countries	all countries
ln water sold	0.643***	0.338***	0.484***	0.400***	0.529***	0.378***	0.522***	0.369***
	(0.051)	(0.034)	(0.128)	(0.140)	(0.048)	(0.066)	(0.047)	(0.061)
ln network length	0.148***	0.191***	0.438***	0.391***	0.508***	0.402***	0.466***	0.391***
	(0.054)	(0.060)	(0.164)	(0.144)	(0.049)	(0.030)	(0.060)	(0.049)
ln wastewater		0.271***		0.101		0.119**		0.145***
		(0.051)		(0.085)		(0.058)		(0.045)
ln network loss		0.041***		0.058**		0.110***		0.083***
		(0.009)		(0.029)		(0.029)		(0.025)
ln population density		0.117		-0.038		-0.024		-0.035
		(0.122)		(0.065)		(0.071)		(0.046)
Rural		0.554		0.315		-0.429***		0.049
		(0.588)		(0.252)		(0.099)		(0.262)
Rural and urban		-0.082***		-0.098**		-0.025		-0.032
		(0.018)		(0.048)		(0.037)		(0.035)
YEAR	-0.005	-0.005	0.001	0.002	-0.029*	-0.026**	-0.018*	-0.016*
	(0.005)	(0.005)	(0.010)	(0.008)	(0.016)	(0.013)	(0.011)	(0.009)
Observations	383	381	682	643	1002	992	1684	1635
Number of firms	71	70	180	173	203	202	383	375
Within R-sq	0.0618	0.212	0.00533	0.0133	0.0424	0.0590	0.0264	0.0403
Between R-sq	0.901	0.887	0.774	0.784	0.930	0.933	0.892	0.896
Overall R-sq	0.885	0.862	0.750	0.769	0.917	0.921	0.890	0.896

The table reinforces our earlier conclusions. First, coefficients of water and wastewater output are similar across countries. Increasing both by 10 percent ceteris paribus leads to about 5 percent increase in electricity consumption, showing very strong returns to scale. The effect of network length, and thus density, is significant in all country groups. This, however, is more important for CIS countries: while a 10 percent increase of the network (given water output) increases use by 1.9 percent in Visegrad countries, this increase is 4 percent in CIS countries. This suggests that network operating costs and thus fixed costs are more important in these countries.

In these regressions network loss is significant, and its coefficient varies across country groups: it seems to be the most important for CIS countries, where 10 percent increase in network loss is associated with 1.1 percent larger electricity consumption. Interestingly, population density and the nature of service area have not been found to be related to energy efficiency. The time trend is significant for CIS countries suggesting about 3 percent increase in electricity efficiency per year.

Next, we study how macro variables are related to electricity efficiency. For this, we include GNI per capita and electricity price to the regression. Note, that we also included country dummies to control for fixed characteristics of the countries, so identification comes from change in income and electricity prices. The results are reported in Table 6. The estimates show a very significant relationship between electricity price and energy efficiency:

increasing electricity prices by 10 percent leads to 4.9 percent decrease in electricity consumption given output. This effect is very strong in CIS countries, but also present to some extent in Visegrad countries: here a 10 percent increase in electricity price is associated with 1.7 percent increase in energy efficiency, suggesting that a lot of the efficiency improvement potential has already been utilized. These results point strongly to the importance of proper electricity prices in motivating firms to become more efficient. If one omits country dummies (unreported) the relationship between electricity prices and efficiency remains similar, but the regressions show a positive relationship between electricity use and GNI/capita.

Table 6 The effect of macro variables

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	V-4	V-4	CEE	CEE	CIS	CIS	all countries	all countries
ln water sold	0.641***	0.334***	0.461***	0.368***	0.594***	0.498***	0.565***	0.451***
	(0.047)	(0.027)	(0.134)	(0.131)	(0.041)	(0.080)	(0.043)	(0.067)
ln network length	0.145***	0.183***	0.458***	0.404***	0.427***	0.367***	0.417***	0.362***
	(0.048)	(0.050)	(0.173)	(0.154)	(0.032)	(0.025)	(0.054)	(0.047)
ln wastewater		0.273***		0.111		0.063		0.105
		(0.044)		(0.076)		(0.086)		(0.064)
ln network loss		0.049***		0.062**		0.085***		0.070***
		(0.009)		(0.031)		(0.020)		(0.019)
ln population density		0.129		-0.029		-0.045		-0.042
		(0.118)		(0.063)		(0.059)		(0.042)
Rural		0.590		0.315		-0.273**		0.129
		(0.590)		(0.261)		(0.109)		(0.245)
Rural and urban		-0.051**		-0.051		0.007		0.002
		(0.021)		(0.069)		(0.057)		(0.034)
ln GNI per capita	0.134	0.119*	0.106	0.164	0.144	0.113	0.059	0.059
	(0.107)	(0.068)	(0.125)	(0.111)	(0.137)	(0.185)	(0.121)	(0.130)
ln electricity price, USD cent/kwh	-0.176***	-0.169*	-0.317	-0.323	-0.673***	-0.592***	-0.548***	-0.493***
	(0.062)	(0.087)	(0.204)	(0.218)	(0.079)	(0.097)	(0.137)	(0.132)
YEAR	0.004	0.004	0.030	0.025	0.037**	0.030	0.043***	0.036***
	(0.019)	(0.015)	(0.029)	(0.026)	(0.017)	(0.020)	(0.013)	(0.013)
Observations	385	381	685	644	1014	992	1699	1636
Number of firms	71	70	180	173	203	202	383	375
Within R-sq	0.0935	0.233	0.0132	0.0228	0.105	0.105	0.0662	0.0720
Between R-sq	0.901	0.890	0.772	0.783	0.931	0.934	0.892	0.897
Overall R-sq	0.885	0.866	0.749	0.770	0.921	0.924	0.893	0.898

We also included three other variables in the regressions. First, we included a dummy whether the service area is hilly, i.e. whether the standard deviation in height is larger than 20 meters (as discussed in Chapter III.3). Second, we included a dummy whether the firm applies secondary treatment for wastewater. Third, we included the (ln) volume of water sold which is treated bulk. We assume that this requires less electricity than water distributed directly to consumers. Table 7 shows the results.

Table 7 The effect of other controls

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	V-4	V-4	CEE	CEE	CIS	CIS	all countries	all countries
ln water sold	0.377***	0.375***	0.383***	0.418***	0.380***	0.385***	0.378***	0.380***
	(0.024)	(0.034)	(0.128)	(0.138)	(0.062)	(0.060)	(0.055)	(0.058)
ln network length	0.175***	0.185***	0.413***	0.411***	0.409***	0.408***	0.396***	0.397***
	(0.053)	(0.063)	(0.156)	(0.157)	(0.030)	(0.026)	(0.051)	(0.049)
ln wastewater	0.264***	0.259***	0.098	0.088	0.119**	0.118**	0.135***	0.140***
	(0.046)	(0.051)	(0.084)	(0.083)	(0.060)	(0.054)	(0.045)	(0.043)
ln network loss	0.040**	0.033***	0.056**	0.058*	0.109***	0.111***	0.083***	0.084***
	(0.020)	(0.009)	(0.027)	(0.030)	(0.031)	(0.031)	(0.026)	(0.026)
height stenderd deviation>20m	0.199**	0.198**	-0.162	-0.092	-0.100	-0.098	-0.112	-0.085
	(0.084)	(0.100)	(0.166)	(0.162)	(0.112)	(0.111)	(0.089)	(0.086)
secondary treatment dummy	0.017	0.052	0.006	0.019	0.032	0.029	0.035	0.031
	(0.167)	(0.154)	(0.061)	(0.055)	(0.038)	(0.042)	(0.028)	(0.035)
ln water sold in bulk, mn m3	-0.021***	-0.022***	-0.020***	-0.023***	-0.008***	-0.008*	-0.011***	-0.011***
	(0.005)	(0.006)	(0.006)	(0.006)	(0.003)	(0.004)	(0.002)	(0.002)
ln population density		0.158*		-0.053		-0.023		-0.040
		(0.086)		(0.072)		(0.069)		(0.047)
Rural		0.497		0.317		-0.417***		0.058
		(0.544)		(0.251)		(0.095)		(0.265)
Rural and urban		-0.098***		-0.098**		-0.014		-0.020
		(0.008)		(0.046)		(0.042)		(0.038)
YEAR	-0.006	-0.004	-0.000	0.003	-0.027*	-0.026*	-0.017*	-0.016*
	(0.005)	(0.004)	(0.008)	(0.008)	(0.014)	(0.013)	(0.009)	(0.009)
Observations	381	381	659	643	992	992	1651	1635
Number of firms	70	70	176	172	202	202	378	374
Within R-sq	0.208	0.254	0.0317	0.0367	0.0775	0.0780	0.0570	0.0577
Between R-sq	0.903	0.903	0.776	0.778	0.937	0.937	0.898	0.899
Overall R-sq	0.884	0.878	0.762	0.768	0.925	0.926	0.900	0.901

The height variable is significant for the Visegrád countries: in these countries a more hilly terrain is associated with 20 percent higher electricity bill, when all other variables are fixed. Selling water in bulk consumes less electricity in all countries. This effect is highly significant and is very precisely estimated.

The regressions do not yield a significant coefficient for secondary treatment of wastewater. While secondary treatment is clearly more energy intensive than primary treatment (or no treatment at all) one can suspect that the companies applying advanced treatment are also the ones which utilize other modern, energy efficient technologies. Since primary treatment results in sewage sludge, which can be turned into biogas, one additional explanation may be that some of the companies with secondary treatment of sewage also generate and internally use energy, thus requiring less energy purchase from the grid.

VI. INTERPRETATION OF THE RESULTS

Using the models resulting from the multiple variable regression analysis, described in the previous chapter, it becomes possible to estimate the energy use of a water utility based on its key operating attributes. Moreover, we can generate a probability range around this estimate and check if the actual energy use of the company falls within this range. If it does then we can assume that its energy use in line with its operating conditions. If actual energy use is above the estimated range then this is either because of a technological or other specification which was not part of our model, or it is because the energy efficiency of the company is lower than what is justified by its circumstances, suggesting that there is substantial room for improvement. If actual energy use is below the estimated range then, again, this may be due to some factor not accounted for in our model, or the utility is highly energy efficient and therefore it should be regarded as a good practice location.

We estimated the energy use for each company for which all necessary data on operating conditions was available. For many utilities, data was available for several years, but we only used the most recent data, as that is usually the best reflection of current practices and according to our experience more recent data is generally more reliable than older data. For each company we used the statistical model of the region in which it belongs, either CEE or CIS, justified by the substantial differences between the two regions.[8] We used the CEE (4) and CIS (6) models from Table 5 in Chapter V.2. We checked for the consistency of using other model specifications described in Chapter V.2 and concluded that for our purposes any of these models are sufficiently good. Two probability ranges were estimated for each company, one with a 95% and the other with a 76% probability level, i.e. these are the probabilities that the established ranges are correct and the actual energy use of the company is within the range. The range with 95% probability was inconclusively wide in many instances, that is why we also opted for a narrower range, at the price of reduced significance. The two ranges together provide a reasonable evaluation of the performance of a company.

---

[8] When the energy use of all companies was estimated with the statistical model covering the whole region (CEE and CIS together) then the total estimated energy use was about 23% lower than actual energy use. This difference is primarily caused by estimating CIS energy use with models which are also based on more efficient CEE water utilities. When the energy use of utilities is estimated with the statistical model of the region where the utility belongs to then the difference between total actual energy use and total estimated energy use is less than 2%.

Table 8 below reviews the position of companies in comparison with their estimated energy use in a country breakdown. The cells of the table contain the number of companies the actual energy use of which is below, above or within the estimated range. Working with a 95% probability level, which results in a rather wide range, most companies, 432 out of 469, will fall within the range. At a 76% significance level the energy use of 329 of the companies can be explained by the examined operating attributes, while 82 companies will have lower energy use than estimated, some of these companies could serve as best practice examples. 58 utilities are likely to have room for energy efficiency improvement even compared to the rest of the companies in their region, which on average still operate at a lower efficiency then their peers in higher income countries. When we consider individual countries, it is worthwhile to focus on countries with a larger sample size. In BiH, Hungary, Kazakhstan, Moldova, Poland, Romania, Russia, Turkey and Ukraine most companies perform as they are expected, and altogether less than 30% of the companies in these countries perform below or above expectations (at a 76% significance level). Of these countries, BiH and Kazakhstan have a fairly high number of well performing companies, but again, we cannot be certain that this is due to high efficiency or some factor which has not been accounted for. In some locations, especially Albania and the Czech Republic, the situation is quite mixed, while in Bulgaria, Croatia and Georgia the results are tilted toward well performing utilities. Especially intriguing is the performance of Georgia, a relatively low income country with a dominance of good performers, suggesting that further analysis of local conditions could be a useful exercise[9].

---

[9] The country profile supplementing the database from Georgia, while useful in general, did not provide an explanation of why energy use may be so low.

Table 8 The position of actual energy use compared to the estimated energy use range (number of companies)

	95% probability range			76% probability range		
	Below range	Above range	Within range	Below range	Above range	Within range
Albania	6	2	44	11	19	22
Armenia	2	0	3	3	0	2
Bosnia and Herzegovina	1	0	16	4	0	13
Bulgaria	3	0	12	5	1	9
Croatia	2	1	15	6	1	11
Czech Republic	1	0	15	3	5	8
Georgia	7	0	13	11	2	7
Hungary	0	0	27	3	2	22
Kazakhstan	3	0	20	6	0	17
Kyrgyz Republic	1	0	6	3	0	4
Macedonia, FYR	0	0	4	0	0	4
Moldova	2	0	38	5	0	35
Poland	0	0	24	2	2	20
Romania	0	0	25	2	2	21
Russia	2	1	81	6	17	61
Slovakia	0	1	2	1	1	1
Turkey	0	0	18	2	2	14
Ukraine	2	0	69	9	4	58
Total	**32**	**5**	**432**	**82**	**58**	**329**

In addition to looking at the number of companies inside or outside the estimated ranges, we can also calculate the volume of energy used by these companies and see how much of that energy use falls into specific categories (Table 9). We can see that Albania, Bulgaria, Croatia, the Czech Republic, Russia, Turkey and Ukraine offer the best chances for energy efficiency improvements, at least based on the sample that we worked with. However, we should keep in mind that the representativeness of the country samples is not supported by available country specific information. Some of the results in the table should be taken with a bit of caution, either because of low sample size (Armenia, Kyrgyz Republic, Macedonia, Slovakia) or because the results are too good to believe (Georgia).

Table 9 The position of actual energy use compared to the estimated energy use range (based on GWh of actual energy use)

		95% probability range			76% probability range		
	Sample size	Below range	Above range	Within range	Below range	Above range	Within range
Albania	52	0.3%	27.5%	72.2%	0.9%	70.5%	28.6%
Armenia	5	1.4%	0.0%	98.6%	33.3%	0.0%	66.7%
Bosnia and Herzegovina	17	2.7%	0.0%	97.3%	4.4%	0.0%	95.6%
Bulgaria	15	1.3%	0.0%	98.7%	7.8%	24.8%	67.4%
Croatia	18	0.5%	30.5%	69.0%	5.1%	30.5%	64.4%
Czech Republic	16	0.4%	0.0%	99.6%	12.0%	24.4%	63.6%
Georgia	20	34.1%	0.0%	65.9%	40.7%	4.6%	54.7%
Hungary	27	0.0%	0.0%	100.0%	8.1%	10.9%	81.0%
Kazakhstan	23	3.2%	0.0%	96.8%	8.2%	0.0%	91.8%
Kyrgyz Republic	7	0.2%	0.0%	99.8%	45.8%	0.0%	54.2%
Macedonia, FYR	4	0.0%	0.0%	100.0%	0.0%	0.0%	100.0%
Moldova	40	0.2%	0.0%	99.8%	0.4%	0.0%	99.6%
Poland	24	0.0%	0.0%	100.0%	5.2%	2.9%	91.9%
Romania	25	0.0%	0.0%	100.0%	1.6%	3.4%	95.0%
Russia	84	0.0%	0.1%	99.8%	1.3%	17.6%	81.1%
Slovakia	3	0.0%	43.6%	56.4%	12.9%	43.6%	43.6%
Turkey	18	0.0%	0.0%	100.0%	1.6%	36.5%	61.9%
Ukraine	71	0.0%	0.0%	100.0%	2.2%	34.6%	63.1%
Total	**469**	**0.6%**	**1.5%**	**97.9%**	**6.2%**	**15.3%**	**78.5%**

It is also possible to evaluate the performance of individual utilities, but since some of the important factors driving energy use, especially on the process level (see Chapter II.1 on literature review) were not possible to quantify, we would not like to single out the performance of any specific utility within the study. Nevertheless, graphical representation of individual values is an informative exercise. Figure 6 below shows the observed and estimated values of CEE and CIS utilities, respectively. Please note that logarithmic scale is applied. If a company is located on the yellow line then its estimated and observed values are equal. The further the value of a utility lies above the line, the more the observed value exceeds the estimated value, i.e. the larger the estimated room to improve energy efficiency. A value below the yellow line tells us that the utility is likely more efficient than its operating conditions would suggest. The message of this figure is very similar to the conclusions already described in connection with Table 8 and Table 9 above, but we have an improved understanding of the dispersion of individual utility values. The figure is also illustrative of the absolute size of companies, the closer a company is to the origin of the chart, the smaller it, and its energy use, is. Utilities in BiH and Turkey, for example, are generally smaller than utilities in Hungary. The utilities of some of the countries, especially the Czech Republic, Hungary, Poland, and to a smaller extent, Romania nicely align with the diagonal line, reinforcing our view that the variation among utilities in these countries is relatively small, there are few companies with abnormally high or low energy intensity.

Figure 6. Observed and estimated energy use of CEE water utilities, logarithmic scale

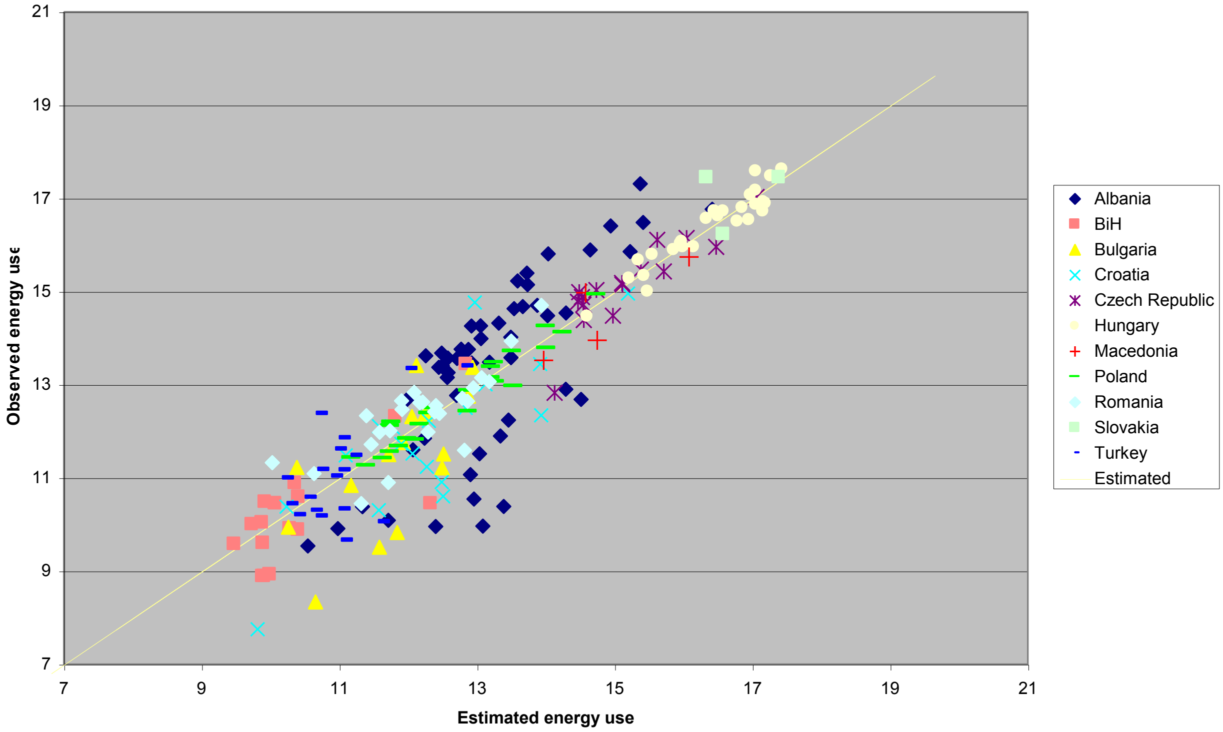


Figure 7 below contains the same information as Figure 6 above, but this time for CIS utilities. The two regions together are represented in Figure 8.

Figure 7. Observed and estimated energy use of CIS water utilities, logarithmic scale

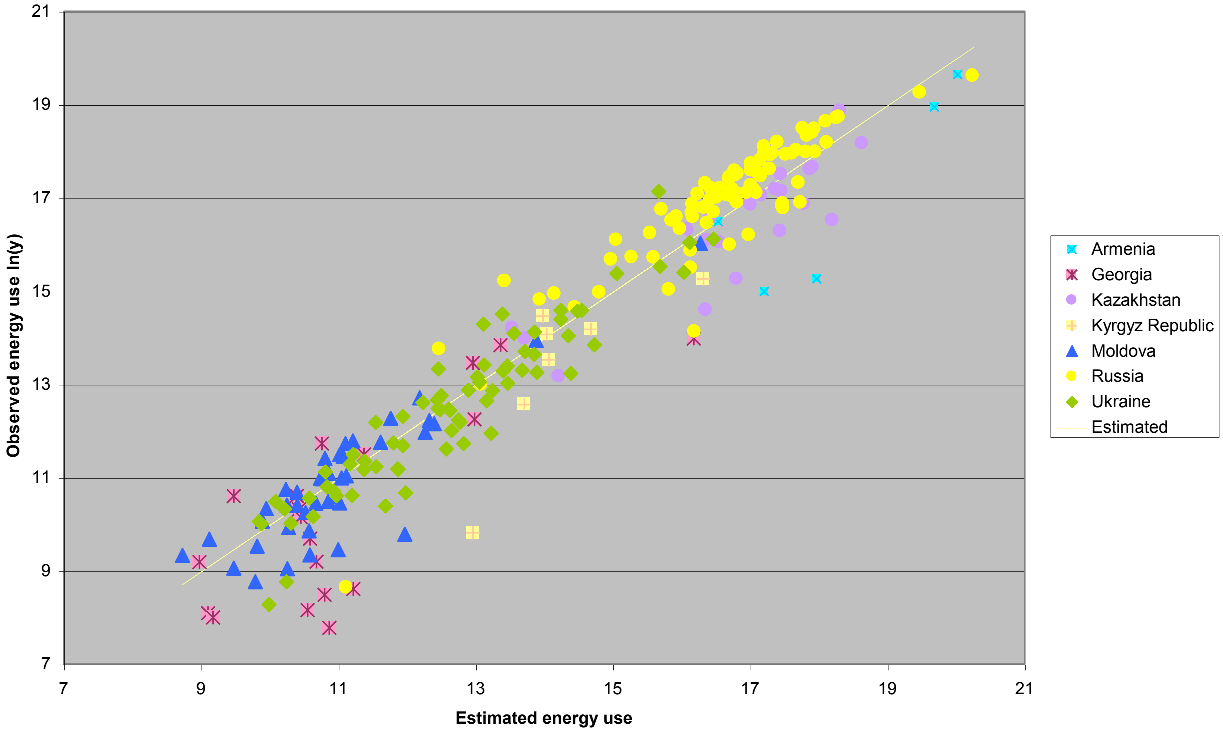
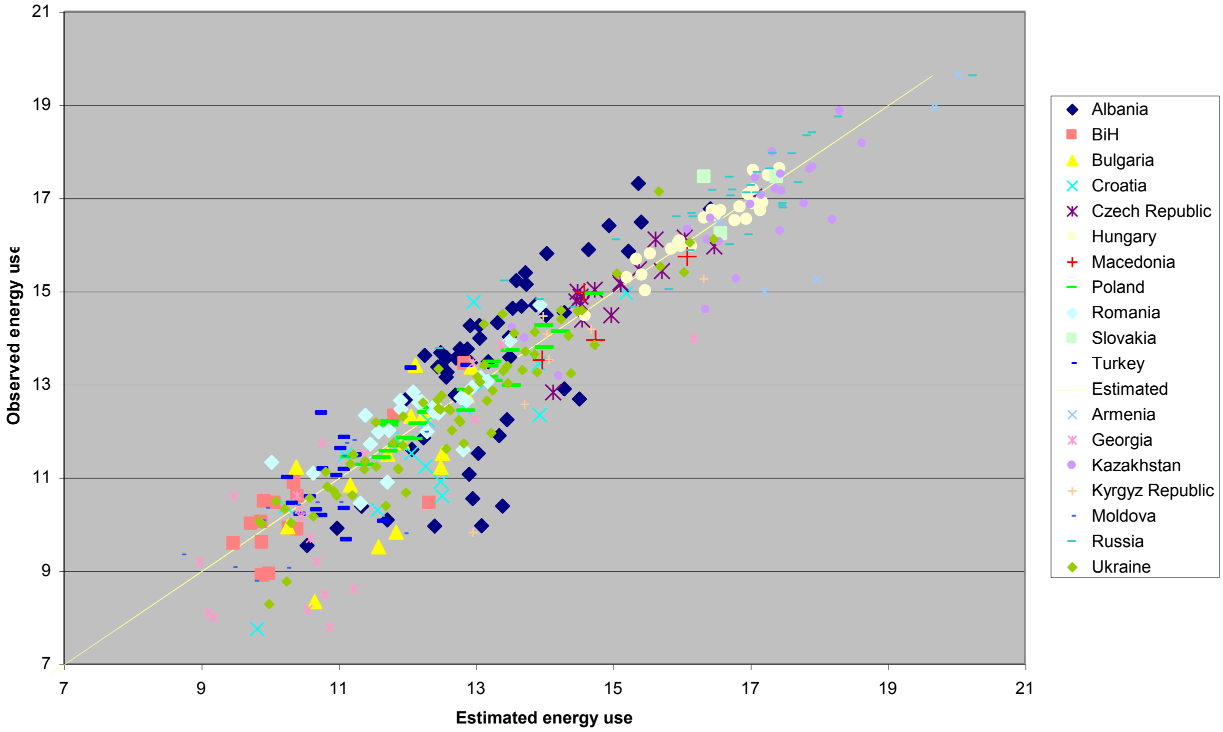


Figure 8. Observed and estimated energy use of CEE and CIS water utilities, logarithmic scale



While many other factors help to fine-tune our results, the two most important factors driving the energy use of water utilities are the country in which they belong and the volume of water delivered. As an illustration, the water sales and actual energy use of the utilities have been graphed in Figure 9 for CEE, and Figure 10 for CIS. We can easily spot country-clusters, and within these clusters higher volumes of water sold usually correspond to higher levels of energy use.

Figure 9. Water sold and observed energy use of utilities in CEE, logarithmic scale

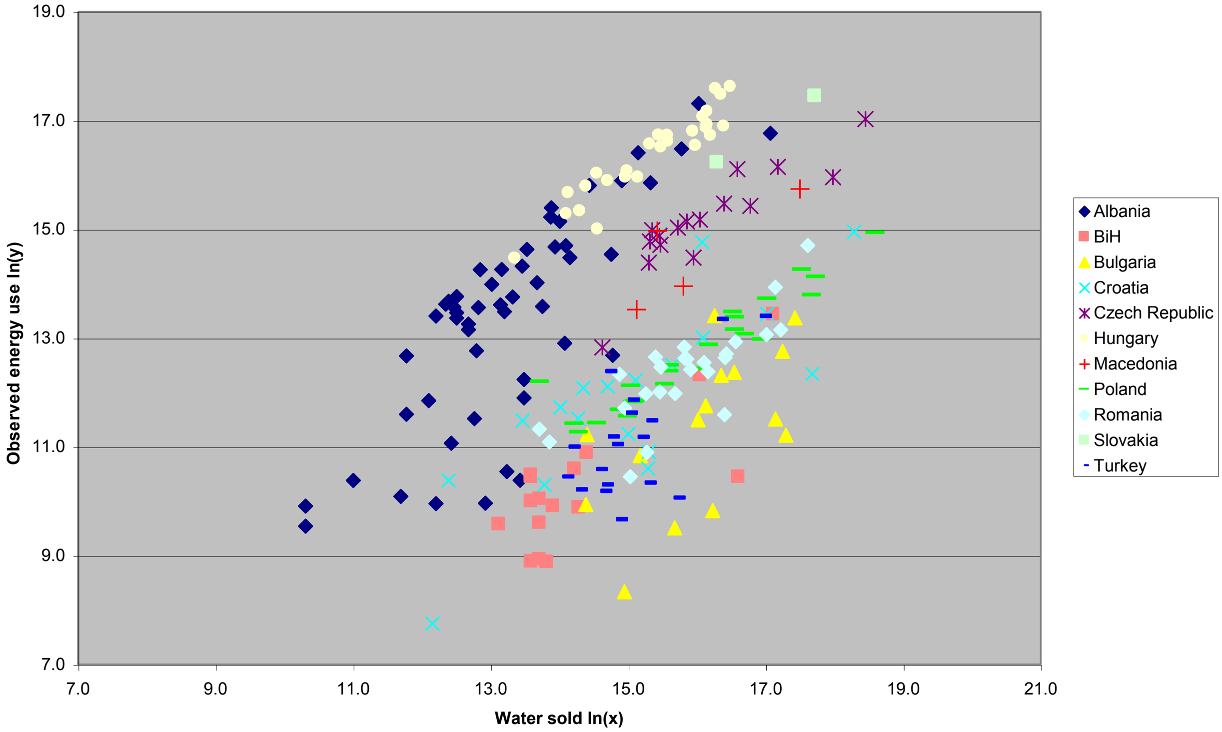
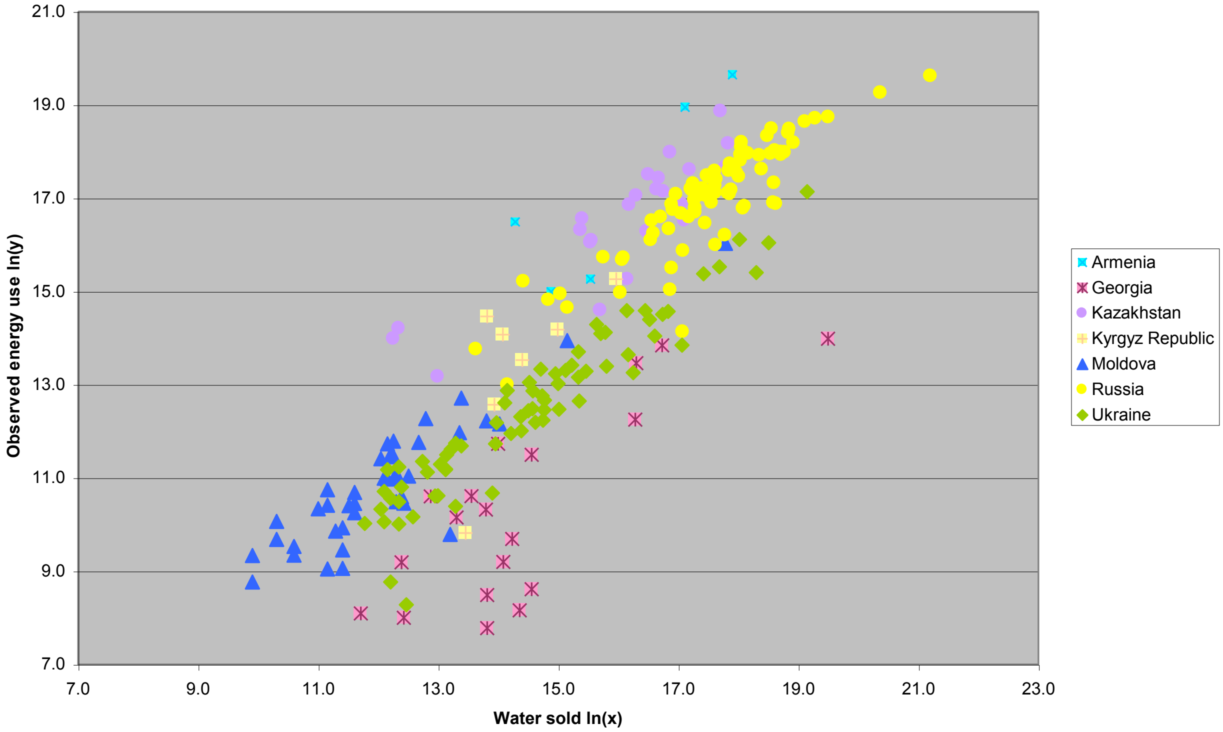


Figure 10. Water sold and observed energy use of utilities in CIS, logarithmic scale



VII. LIST OF SOURCES

Abbott, Malcolm and Bruce Cohen. Productivity and efficiency in the water industry. Utilities Policy 17 (2009) p. 233-244.

Armar, Amarquaye and Pedro Paulo da Silva Filho. Reducing energy costs in municipal water supply operations. „Learning-while-doing” energy m&t on the Brazilian frontlines. ESMAP. 2003.

Bisztray, M, A. Kis, B. Muraközy and G. Ungvári. Statistical Analysis of the Performance Data of Central and Eastern European Water Utilities. 2009a.

Bisztray, M, A. Kis, B. Muraközy and G. Ungvári. A víziközművek adottságai és teljesítményük közötti összefüggések vizsgálata statisztikai módszerekkel [Statistical Analysis of the Relationship among the Performance and Operating Conditions of Water Utilities. In Hungarian]. REKK. 2009b.

Byrnes J., *et. al*. The relative economic efficiency of urban water utilities in regional New South Wales and Victoria. Resource and Energy Economics.

Carlson, Steven W. and Adam Walburger. Energy Index Development for Benchmarking Water and Wastewater Utilities. AWWA Research Foundation. 2007.

Elliott, Todd, Benjamin Zeier, Irene Xagoraraki, and Gregory W. Harrington. Energy Use at Wisconsin's Drinking Water Facilities. Energy Center of Wisconsin. July 2003.

Gay Alanis, Leon F. Measuring Energy Efficiency of Water Utilities. Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State University. 2009.

Haecky, Pia and Roberto Perco. Wastewater treatment process optimization: energy savings with aeration control and high efficiency technology. In Water 21. October 2009.

Ijjaz-Vasquez Ede Jorge. Uzbekistan Energy Efficiency in Urban Water Utilities of Central Asia. ESMAP / The World Bank Group. 2005.

Jentgen, Lawrence A. *et. al*. Water Consumption Forecasting to Improve Energy Efficiency of Pumping Operations. AWWA Research Foundation. 2007.

Landon, Dave. Energy Efficiency Benchmarking – Presentation for the World Bank. WRc Research Foresight Partnership Energy Efficiency Benchmarking Programme. October 2009.

Raucher, Robert S. *et. al*. Risks and Benefits of Energy Management for Drinking Water Utilities. AWWA Research Foundation. 2008.

SAIC (Science Applications International Corporation). Water and Wastewater Energy Best Practice Guidebook. 2006.

US EPA. Ensuring a Sustainable Future: An Energy Management Guidebook for Wastewater and Water Utilities. January 2008.

Zakkour P.D. *et. al*. Developing a sustainable energy strategy for a water utility. Journal of Environmental Management. 2002. Vol 66. p. 105-125.

VIII. ANNEX ON DATA CLEANING

Before the analysis we cleaned the raw IBNET database. This included two types of corrections. We replaced erroneous data by the correct one if it could be done in an unambiguous way, i.e. if it was supported by other relating data. In case no clear corrections were possible, we indicated the definitely mistaken data as a missing observation.

The main corrections are described below. Not all of the variables mentioned here were eventually used for the statistical analysis, but this is only evident in hindsight, as the analysis was an multi-step process looking at the role of a suite of different variables.

There were a few cases where the number of total population living in the service area (30 and 30a) was smaller than the given number of population served (40 and 70). As according to the definition of the data the latter has to be a subgroup of the former, we used the given number of total population (30 and 30a) for both variables.

The indicator “Type of service provided” (32a) was brought in line with other data provided. If there were data given both for water and sewerage service, the utility was considered to be of type 3 (“both water and sewerage service”) if originally it was in category 1 (“only water service”) or 2 (“only sewerage service”). In case no data was provided concerning sewerage service the utility was included in the type 1 group (“only water service”), and in the type 2 group (“only sewerage service”) if the opposite was true.

If in one year the total number of staff was smaller than the value obtained by adding the numbers of staff connected to water and sewerage service, the numbers were corrected according to previous years’ data. Corrections were also done when the given number of staff was considerably lower than in previous years’ data.

In some cases connections with operating meter (53) were reported to be somewhat more numerous than the total number of connections (41). As the difference was not very big, the total number of connections was increased to the value of connections with meter. The same correction was done when the volume of water produced (55) was lower than the volume of water sold (59). The difference was not considerable here as well, thus volume produced was increased to the level of volume sold. However, in those cases where volume of water consumed metered (58) was higher than the volume of sold (59), the metered quantity was reduced to the level of volume sold, in order to bring it in line with other data (volume sold by customer categories).

It also happened that total reported volume of wastewater collected (81a) was clearly erroneous compared to related measures of volume collected by customer categories (81b, 81c), operating revenues (90d) or number of population served (70). If it was clear that the mistake came from using an incorrect order of magnitude, it was corrected; else the data was considered as missing. Similar order of magnitude problems were identified and corrected if possible at the number of sewer connections data (71). In those cases when total volume of wastewater collected (81a) was lower than the volume collected from residential customers (81b), the less reliable (typically the latter) was corrected, as the difference was always quite small.

There was a clear mistake when reporting duration of supply in two cases which were also corrected based on previous years' data.

The size of operational expenses (94) was also checked by comparing it to the separate measures of expenses for water and sewerage service (94a, 94b), the different cost categories (96, 97, 99) and to operating revenues (90). If there was a clear mistake in the order of the data, corrections were done based on data from other years. In case of no possible unambiguous corrections data were labeled as missing. Some firms reported lower total operational expenses (94) than the sum of water and sewerage expenses (94a, 94b). It was corrected if possible based on previous years' data or considered as missing otherwise. Where the given amount of total operating expenses (94) was lower than any of the subcategories labor, electrical energy or contracted out services costs (96, 97, 99), but the total value seemed to be correct, the given subcategory was changed to 'missing data' if not correctable unambiguously. As electrical energy costs (97) are in the focus of our paper, a special attention was devoted to these data. In some cases the order of this measure was found far too low compared to other elements of costs. These few cases were considered as missing data.

Similar comparisons were carried out regarding total operating revenues (90). The order was checked by comparing it to subcategories (90c, 90d) or similar measures (90a, 90b, 94) and corrected if it was clear how to proceed. Otherwise erroneous data were labeled as missing. According to the guidelines total operating revenues (90) should be equal to the sum of water and sewerage operating revenues (90c and 90d). In some cases inconsistency was found, as these were different, but total operating revenues (90) were the same as the sum of total billings to residential and industrial-commercial customers (90a, 90b), which should rarely be true. Consequently total operating revenues (90) were considered as missing.

When the total value of gross fixed assets (112) was not reported but data were given separately for water and sewerage services (112a and 112b), we used the sum of these two (112a, 112b) as the total value (112).

There were some types of data, where the value of zero obviously can’t be realistic. These include population served (40), volume of water produced or sold (55, 59), volume of water sold to different types of customers being all zero (59a, 59b, 59c, 59d) and length of distribution network (54) when there were other data indicating that the firm provides water supply. The case was similar with sewerage service, regarding population served (70), total volume collected (81a) and length of the sewer system (74). Monetary data like total operating revenues (90), total cash income (91) or total operational expenses (94) can’t be zero either. This is also true to subcategories ‘water’ or ‘wastewater’ (90c, 90d, 94a and 94b) provided there exists such a service at the firm. Finally billings for a given customer category (90e, 90f, 90g, 90h, 90i, 90j) can’t be zero either if before there was quantity sold or collected indicated in that category (59a, 59b, 59c, 59d, 81b and 81c respectively). Consequently all these having zero values were transformed to ‘missing data’.