Efficiency Evaluation of Water Sector in the Czech Republic: Two-Stage Network Dea

Emília Zimková[1] | *Matej Bel University, Banská Bystrica, Slovakia*
Petra Gurčíková[2] | *Matej Bel University, Banská Bystrica, Slovakia*
Michaela Vidiečanová[3] | *Matej Bel University, Banská Bystrica, Slovakia*
Ľubomír Pintér[4] | *Matej Bel University, Banská Bystrica, Slovakia*
Colin Lawson[5] | *University of Bath, Bath, United Kingdom*

Received 15.6.2023, **Accepted** (reviewed) 21.8.2023, **Published** 15.12.2023

Abstract

The water and wastewater services, usually provided in a monopoly regime, do not offer the operators natural incentives toward efficiency and innovation. Therefore the main aim of the regulatory institutions is to stimulate a competitive environment. The contribution measures technical efficiency of 21 water and waste water companies in the Czech Repulic. For the period 2018–2020, the two-stage slacked-based model (SBM) by Kaoru Tone and Miki Tsutsui (2009) was applied. The results of this study are heterogeneous. Only one company out of 21 can be identified as an overall technically efficient unit during all three analyzed years. It is Vodohospodárská společnost Olomouc (VSO) followed by Pražské vodovody a kanalizace (PVK) that is very close to full technical efficiency. Our results therefore reveal a strong potential for the decrease of ineficiency of the water sector in the Czech Republic. Another important outcome is the fact that regulation of the water industry in the Czech Republic is highly fragmented.

Keywords	***DOI***	***JEL code***
Performance measurement, optimization, regulation, water industry, data envelopment analysis, Network SBM, Covid-19	*https://doi.org/10.54694/stat.2023.26*	*C01, D22, D42, L51*

[1] Department of Finance and Accounting, Faculty of Economics, Matej Bel University, Tajovského 10, 975 90 Banská Bystrica, Slovakia. E-mail: emilia.zimkova@umb.sk, phone: (+421)484466322. ORCID: <https://orcid.org/0000-0003-1648-8103>.

[2] Department of Quantitative Methods and Information Systems, Faculty of Economics, Matej Bel University, Tajovského 10, 975 90 Banská Bystrica, Slovakia.

[3] Department of Finance and Accounting, Faculty of Economics, Matej Bel University, Tajovského 10, 975 90 Banská Bystrica, Slovakia.

[4] Department of Finance and Accounting, Faculty of Economics, Matej Bel University, Tajovského 10, 975 90 Banská Bystrica, Slovakia. E-mail: lubomir.pinter@umb.sk, phone: (+421)484466325.

[5] Department of Economics, Faculty of Economics, University of Bath, Claverton Down, Bath BA2 7AY, UK. E-mail: hsscwl@bath.ac.uk, phone: (+44)1225388388.

INTRODUCTION

For more than 20 years, national regulators of network industries in many countries have been using benchmarking tools. These instruments are not used by national regulators in Central European countries yet. An issue of network industries regulation became heavily discussed topic in the professional as well as the wider public. The intensity of interest has increased over the past years, under the influence of the financial crisis and the Covid-19 pandemic. The importance of network industries was reinforced by Russia's aggression in Ukraine, but also by the increasingly intense climate crisis.

Regulated network industry entities usually offer electricity, gas, heat and water. These are commodities that significantly affect not only the consumer basket of households, but also all economic units. In our contribution, we will focus on research in the water segment, which, despite its vital importance, is absent in the academic literature in Central Europe. In addition, the ongoing climate change clearly confirms the exceptionality and rarity of this commodity.

Fresh water is, together with the sun, vital and its value will increase every year. Its share in the total volume of water on Earth is only 2.5%, up to 96.5% of the total volume of water on Earth is in form of oceans. The rest is in form of a saline ground-water (0.39%) and saline lakes (0.07%) (Gleick, 1993). Water research from an economic point of view is one of the areas that are extremely important, yet knowledge in this area is not sufficient.

From the economic theory point of view in the area of drinking water production, distribution and supply and wastewater collection and treatment, water companies, as well as other operators of public water supply and public sewerage systems, are natural local monopolies. In a given locality, there is always one supplier defined by its operating territory, or by operated water supply or sewerage systems, without the possibility to choose by consumers.

Thus, the water and wastewater services (WWS), usually provided in a monopoly regime, do not offer the operators natural incentives toward efficiency and innovation in opposition to competitive markets. The fostering of a competitive environment in the WWS is one of the main aims of the regulatory institutions. Regulators more and more employ benchmarking as a way to create markets and, therefore to encourage the WWS to be more productive. Benchmarking can be briefly defined as a process of seeking excellence through the systematic comparison of performance measures with reference standards (Marques, 2011). In our contribution the Data envelopment analysis is used to benchmark water providers operating in the Czech Republic in years 2018–2020.

Among main advantages of benchmaring use in the WWS, the following can be pointed out: [i] strong incentives are provided to operators to be efficient and innovative mitigating the costs of operation and capital expenses; [ii] on-going pressure is put on the water utilities to improve service quality; [iii] a fairer recovery of costs and of the capital investments is assured, and [iv] an increase of transparency and sharing of information minimizing its asymmetry between different stakeholders (especially between the regulator and the operator) (Marques, 2006).

The supervision of the water management in the Czech Republic is surprisingly fragmented. It is mainly carried out by the Ministry of Finance and the Ministry of Agriculture, but the Ministry of the Environment, the Ministry of Health, the Ministry of Transport and the Ministry of Defense also have partial competences. Every year, the Ministry of Finance oversees the creation of the prices of drinking and waste water. The Ministry of Agriculture ensures the regulation of water companies, supervises compliance with the binding rules agreed by the Ministry of Finance, collects data on the costs of water and wastewater companies and carries out inspections of WWS. It ensures that customers know who to contact with complaints about water companies when cooperation is needed.

The Department of Water Protection at the Ministry of the Environment covers the protection of the quantity and quality of surface and underground water, protection against floods, planning in the field of water at the national and international level, international cooperation in the field of water protection, economic, financial and administrative instruments for water protection, the creation of legislation and standards in the field of water protection.

After privatization in 1993, 11 state water companies in the Czech Republic were divided into 40 regional water companies and more than 1 200 small water intermediaries. In 2020, there were 7 729 owners and 3 041 operators of water companies in the Czech Republic. The number of owners increased by 249 compared to 2019, and the number of operators increased by 49 (Ministry of Agriculture, 2022).

Due to the high number of owners and operators of water infrastructure, several associations dealing with water management issues were created. The most important position is held by the organization SOVAK, which brings together physical and legal entities whose activities include the supply, removal and purification of waste water. The company includes the owners, managers, operators of water supply and sewerage systems for the public. The main goal of SOVAK is to formulate and defend the common interests of all members, to ensure the coordination of activities and services according to the needs and interests of members, to cooperate with professional organizations (EurEau – European Union of National Associations of Water Suppliers and Wastewater Service Providers) and to publish a professional magazine. The Association for Water of the Czech Republic and the Association of Owners of Water Infrastructure also aim to bring together water companies.

The regulation of water management in the Czech Republic is extremely fragmented compared to other countries, as it is ensured by six ministries. In the Czech Republic. In the Czech Republic, there is no independent professional regulatory body for water management, and the regulation of network sectors has long been perceived in the Czech Republic as the regulation of electricity, gas and heat.

The production process of water management companies in the past period was significantly affected by the Covid-19 pandemic and the measures taken by governments in an attempt to mitigate the spread of the pandemic. In the Czech Republic, among the most significant impacts of the Covid-19 pandemic on the activities of water companies were: restrictions on tourism, including the closure of accommodation and restaurant facilities, restrictions on the operation of schools and offices, restrictions on contact with customers, the expansion of work from home, and the adoption of adequate hygiene measures. Absences of employees due to the disease Covid-19, or Quarantines in case of infection of a close person caused a difficult organization of work, which was manifested by reduced reconstruction of property, with the exception of the emergency situations elimination.

The research in this paper focuses on the technical efficiency of 21 water companies operating in the territory of the Czech Republic, which provide abstraction, treatment, delivery, cleaning of water for more than two thirds of economic subjects in the Czech Republic. We apply two-stage slacked-based model (SBM) approach of data envelopment analysis (DEA) and evaluate the production process in water companies operating in the territory of the Czech Republic in 2018–2020.

The paper is structured as follows. The first part contains a brief literature overview, the second part provides description of data and model specifications, the third part reports main research findings that are discussed and in the final one concludes.

1 LITERATURE REVIEW

In the following part of the paper, we will summarize empirical studies dealing in recent years with the issue of efficiency evaluation based on the application of the DEA method in water management.

The paper of Thanassoulis (2000a) provides an introduction to the basic DEA models for assessing efficiency under constant and variable returns to scale. It also outlined the use of DEA by OFWAT, the regulator of water companies in England and Wales. The best of the effciency rating offered by DEA or OLS regression were allocated to the water utilities. The efficiency ratings had an impact on the cap placed on the company´s charges. Another paper writen by Thanassoulis (2000b) details the use of

DEA to estimate potential savings in the specific context of water distribution and discussed the use of the results obtained.

Liu and Fukushige (2019) investigated the efficiency of water utilities in Japan using a DEA model and regression analysis. The authors implement a two-stage analysis method, which involves measuring the relative efficiency of water supply and sewerage services using DEA in the first stage, and then, based on regression models, the authors examine the relationships between prices and estimated efficiency scores.

In their study, the authors Molinos-Senante and Maziotis (2021) examine the efficiency of water and sewerage companies in Chile during the years 2010–2018. This study estimates the cost-effectiveness of the water sector using the stochastic non-parametric data envelopment (StoNED) method, which combines the advantages of data envelopment analysis (DEA) and stochastic frontier analysis (SFA). The results from this study also indicate the need to consider the quality of service for the set water tariffs. The study also showed that public water companies showed higher price efficiency, followed by fully private and finally concession water companies. On the other hand, when the authors analyzed the trend of cost efficiency, the results showed that full private water companies showed an upward trend in their efficiency, while public water companies deteriorated their efficiency.

Another group of authors, Lombardi et al. (2019) conducted an empirical analysis using DEA in the Italian water sector. The study focuses on a selected sample of 68 Italian water companies between 2011 and 2013. The authors found that public water companies have the highest efficiency, purchasing and employing inputs more efficiently, compared to mixed or private firms. Considering water loss in research, the study shows that companies located in the north of Italy are more efficient than those operating in the center and south. Also, small companies showed better net efficiency results, followed by large and extra large companies.

The efficiency of Mexican water companies was analyzed by Salazar-Adams (2021) using double bootstrap DEA. In the first stage, he calculated the efficiency of each company based on a set of inputs and outputs, and in the second stage, the efficiency score is regressed against a set of explanatory variables that affect the efficiency of water companies. In his study, the author concludes that decentralization from the state to the municipalities in Mexico has not significantly increased the efficiency of water utilities because municipal utilities are as efficient as those run by the state. However, the water reform paved the way for new organizational schemes such as inter-municipal enterprises and privately managed enterprises. Intermunicipal enterprises in the sample are on average more efficient than state and municipal enterprises. Several privately managed companies in the sample are, on average, the most efficient type of water utility in Mexico. A possible explanation is local regulation, which compensates for the lack of institutional capacity that often occurs in developing countries.

A study by Liang et al. (2021) developed an improved two-stage network DEA analysis model assuming variable returns to scale in terms of both weights and solution methods, which determined the weights of each stage with the share of input resources. In particular, they measured the overall efficiency of water resource systems, water use efficiency, and wastewater treatment efficiency of 11 provinces in western China from 2008–2017. A panel Tobit regression model was used to further analyze the influencing factors of total efficiency, water use efficiency and wastewater treatment efficiency.

Another group of authors Zhou et al. (2018) investigated the efficiency of water management in China based on a non-radial non-oriented DEA model. The Slacks-Based Measure (SBM) model can simultaneously optimize required inputs and required outputs and project each unit to the "farthest" point on the efficient frontier.

Our contribution is the first empirical study on the technical efficiency of the water and waste water companies in the Czech Republic. To assess the technical efficiendy of water companies, an advanced Network SBM (slack-based network DEA model, variable return to scale) is used.

2 DATA AND MODEL SPECIFICATION

2.1 Data specification

As part of the analysis of technical efficiency, we analyze 21 private water companies operating in the territory of the Czech Republic: Pražské vodovody a kanalizace (PVK), Severočeské vodovody a kanalizace (SVK), Severomoravské vodovody a kanalizace Ostrava (SVKO), Brněnské vodárny a kanalizace (BVK), ČEVAK (CEV), Vodárenská akciová společnost, a.s. Brno (VAS), Ostravské vodárny a kanalizace (OVK), Stredočeské vodárny (SCV), Vodárna Plzeň (VPL), Vodárny a kanalizace Karlovy Vary (VKKV), Královéhradecká provozní (KHP), Vodovody a kanalizace Hodonín (VKH), Vodovody a kanalizace Mladá Boleslav (VKMB), Vodovody a kanalizace Břeclav (VKB), Vodovody a kanalizace Přerov (VKP), Vodovody a kanalizace Vsetín (VKV), Vodovody a kanalizace Kroměříž (VKK), Vodohospodářská společnost Rokycany (VSR), Vodohospodářská a obchodní společnost (VOS), Vodohospodářská společnost Benešov (VSB), Vodohospodářská společnost Olomouc (VSO).

To perform the efficiency analysis, we use two different types of variables, financial and physical. We drew data on financial variables from the available financial statements of companies, primarily from balance sheets and profit and loss statements and data regarding physical variables were gained from the annual reports of individual companies. Table 1 characterizes the selected variables of the model, which represent individual inputs, outputs and intermediate products. The selection of variables was based on the empirical studies listed above.

Table 1 Description of variables

Variable	Notation	Description
Operating costs	OPEX	Costs associated with economic activity, in thousands CZK
Investment	I	Investments into water infrastructure, in thousands CZK
The length of the water supply network	LN	The length of the water supply network without connections, in km
Volume of invoiced drinking water	W	Volume of invoiced drinking water intended for implementation, in m^3
Number of customers	CUS	Number of customers supplied with drinking water

Source: Authors

Table 2 presents the descriptive statistics of the variables of the water companies for the year 2020, and Tables 3 and 4 show the descriptive statistics for the years 2019 and 2018.

In 2020, the operating cost variable reaches an average value of approximately 1 410 649 thousand CZK. There are considerable differences in the minimum and maximum values for all monitored variables. As for the average value of investments, in 2020 they represented 131 308 thousand CZK. The average

Table 2 Descriptive statistics of variables in 2020

2020	OPEX	I	LN	W	CUS
Mean	1 410 649.71	131 308.71	2 218.42	16 441.71	325 807.71
Median	766 684	96 440	1 133	8 369	169 482
Standard Deviation	1 815 278.27	157 739.16	2 345.14	21 345.89	356 914.17
Minimum	48 567	2 319	288.95	1 094	22 500
Maximum	7 621 119	693 962	9 724	91 239	1 330 000
Count	21	21	21	21	21

Source: Authors

length of the water supply network in 2020 was 2 218 km. The average value of supplied drinking water during 2020 is 16 441 m^3. Compared to 2019, the observed value decreased slightly. The average number of customers who are supplied with drinking water is 325 808 in 2020. We can observe higher standard deviations of all variables, which are caused by the different sizes of water companies.

Table 3 Descriptive statistics of variables in 2019

2019	OPEX	I	LN	W	CUS
Mean	1 351 443.38	125 721.05	2 220.32	16 921.19	324 980.33
Median	739 950	85 833	1 130	7 265	168 340
Standard Deviation	1 708 483.89	140 866.20	2 336.98	22 608.34	354 653.28
Minimum	47 969	2 667	290.63	1 076	22 670
Maximum	7 039 511	665 260	9 705	97 190	1 317 000
Count	21	21	21	21	21

Source: Authors

Table 4 Descriptive statistics of variables in 2018

2018	OPEX	I	LN	W	CUS
Mean	1 251 179.05	115 179.24	2 205.12	16 950.67	323 162.86
Median	705 075	91 457	1 127	7 005	167 119
Standard Deviation	1 499 535.03	120 493.84	2 322.72	22 593.11	351 508.42
Minimum	44 483	3 401	290.69	1 174	22 583
Maximum	5 838 638	539 701	9 670	97 746	1 300 000
Count	21	21	21	21	21

Source: Authors

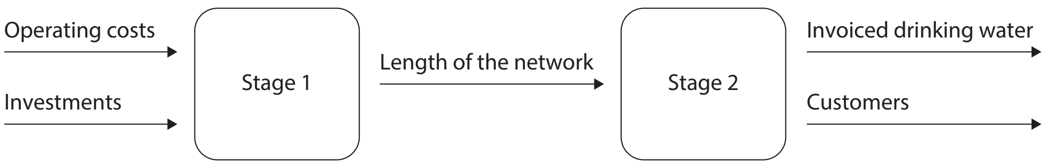
The selection of inputs and outputs was influenced by availability of the data and by empirical studies of other authors. Empirical studies most often consider operational costs, employee costs and capital costs, or investments as inputs. Among the traditional outputs, the authors include the volume of supplied drinking water and the number of customers connected to the public water supply. Some authors consider the length of the water supply network as input, others as output. In our research, we apply the network DEA model, which refers to the length of the network as an intermediate product.

To analyze the efficiency of water companies in the Czech Republic, we use a two-level network structure. The first phase represents the costs of maintenance and operation of the infrastructure, and the second phase is the use of the network for the supply of drinking water to customers. In the first phase, the water company must cover the costs of operation and maintenance. The costs include expenditure on employee wages, energy consumption, capital employed and are the inputs of the first stage. The mentioned expenses enable the infrastructure, which in our case is the length of the water supply network, to be functional. Thus, the infrastructure represents the output of the first phase. From a cost perspective, a water company is efficient if it is successful in operating and maintenance activities using minimum costs. In the second phase, the water company uses the infrastructure for water supply. Using the network DEA model, we can therefore calculate the cost efficiency of the enterprise, the efficiency of water service provision and the overall efficiency of the process. The length of the network in this model represents the connection between the mentioned two processes. In the first phase, the length of the network enters the process as an output, and in the second process, the length of the network is represented as an input. In the research, the operating costs (OPEX) and investments (I) of the water companies appear as the inputs of the first phase. The volume of invoiced drinking water (W) and the number of customers connected to the public water supply (CUS) are used as outputs in the second phase. The length of the network (LN) is considered an intermediate product, which is an output in the first phase and an input in the second phase.

The first stage shows how the company maintains its infrastructure by spending the minimum cost (cost efficiency), and the second stage shows how it utilizes its infrastructure to deliver water and wastewater services to its customers.

Figure 1 represents the given network model.

Figure 1 Two stage network DEA model



Source: Authors

When using the network SBM model, it is important to assign weights to individual divisions. We consider both phases to be equally important, so we decided to give them the same weight of 0.5 and 0.5, since the cost management process of the company and the process of providing water services to its customers are the basic tasks of water companies. An equally important issue is determining the connection between individual divisions. According Tone and Tsutsui (2009), there are 4 types of links: a free link, in which connected activities are under the control of the company while maintaining continuity between input and output. Another type is a fixed link, where the linked activities are unchanged and the intermediate product is not under the control of the company. There are two more types of less used links, so called good link and bad link. In our analysis, we use a free link, as each water company can guide the length of the water network.

2.2 Model specification

Jablonský and Dlouhý (2015) cluster the stages of the production process into serial, parallel or their combination. The serial model assumes a multi-stage production process in which a certain output represents the input to the next stage.

In our study, a two-stage network DEA model is used. The efficiency of the 1st and 2nd level is defined as follows:

$$\max \theta_0^{\,1} = \frac{\vec{w}'\,\vec{z}_0'}{\vec{v}'\,\vec{x}_0'} \qquad \max \theta_0^{\,2} = \frac{\vec{u}'\,\vec{y}_0}{\vec{w}'\,\vec{z}_0}, \tag{1}$$

under conditions:

$$\vec{w}'\vec{z} - \vec{v}'x \le \vec{0}' \qquad \vec{u}'\vec{y}_0' - \vec{w}'\vec{z} \le \vec{0}'$$
$$\vec{v}' \ge \vec{0}',\ \vec{w}' \ge \vec{0}';\ \vec{u}' \ge \vec{0}'$$
$$\vec{w}'\vec{z} - \vec{v}'x \le \vec{0}' \qquad \vec{u}'\vec{y}_0 - \vec{w}'\vec{z} \le \vec{0}'$$
$$\vec{v}' \ge \vec{0}',\ \vec{w}' \ge \vec{0}';\ \vec{u}' \ge \vec{0}'.$$

The overall efficiency can be expressed as:

$$\max \theta_0^{\,0} = \frac{\vec{u}'\,\vec{y}_0}{\vec{v}'\,\vec{x}_0'}, \tag{2}$$

under conditions:

$$\vec{u}'Y - \vec{v}'X \le \vec{0}'$$
$$\vec{v}' \ge \vec{0},\ \vec{u}' \ge \vec{0}.$$

Assuming that the output of the 1st stage is also the input of the 2nd stage, the overall efficiency is expressed by the following equation:

$$\theta_0^{\,0} = \frac{\vec{w}'\,\vec{z}_0'}{\vec{v}'\,\vec{x}_0} \times \frac{\vec{u}'\,\vec{y}_0'}{\vec{v}'\,\vec{x}_0} = \frac{\vec{u}'\,\vec{y}_0'}{\vec{v}'\,\vec{x}_0}, \tag{3}$$

under conditions:

$$\vec{u}'Y - \vec{w}'Z \le \vec{0}'$$
$$\vec{w}'Z - \vec{v}'X \ge \vec{0}'$$
$$\vec{v}' \ge \vec{0},\ \vec{u}' \ge \vec{0},\ \vec{w}' \ge \vec{0}.$$

In the case of writing the model as a linear programming problem, we get the following form:

$$\max \theta_0^{\,0} = \vec{u}'\,y_0, \tag{4}$$

under conditions:

$$\vec{v}'\vec{x}_0 = 1$$
$$\vec{u}'Y - \vec{w}'Z \le \vec{0}'$$
$$\vec{w}'Z - \vec{v}'X \ge \vec{0}'$$
$$\vec{v}' \ge \vec{0},\ \vec{u}' \ge \vec{0}.$$

If $\vec{v}'^{*}$, $\vec{u}'^{*}$,$\vec{w}'^{*}$, represent an optimal solution, we express the overall efficiency of the 1st and 2nd stages as follows:

$$\theta_0^{\,1} = \frac{\vec{w}'^{*}\,\vec{z}_0}{\vec{v}'^{*}\,\vec{x}_0}$$
$$\theta_0^{\,2} = \frac{\vec{u}'^{*}\,\vec{y}_0}{\vec{w}'^{*}\,\vec{z}_0} \tag{5}$$
$$\theta_0^{\,0} = \frac{\vec{u}'^{*}\,\vec{y}_0}{\vec{v}'^{*}\,\vec{x}_0},$$

where: X = input matrix, Y = output matrix, Z = intermediate product matrix, $\vec{x}_0$ = input´s vector of DMU, $\vec{y}_0$ = output´s vector of DMU, $\vec{z}_0$ = intermediate product vector of DMU, $\vec{v}$ = input weight vector, $\vec{u}$ = output weight vector, $\vec{w}$ = intermediate product weight vector, $\theta_0^{\,0}$ total efficiency of DMU, $\theta_0^{\,1}$ efficiency of the first stage of DMU, $\theta_0^{\,2}$ efficiency of the second stage of DMU.

While the traditional DEA model cannot systematically analyze the relationship between the overall efficiency and the efficiency of each stage, the Network SBM model considers the interactions between different stages and can integrate the efficiency evaluation of each network node in the system with the overall efficiency evaluation of the system. Tone and Tsutsui (2009) points out that it is one of the methods applicable to the comprehensive assessment of structural efficiency within the DMU.

3 RESULTS AND DISCUSSION

Table 5 shows the technical efficiency of water companies measured by the Network SBM model (VRS) for the years from 2018 to 2020. The first part of the table represents the efficiency of the 1st phase, which represents the operational management process in the area of costs. In the 1st phase, the inputs were operating costs and investments. These expenses serve to ensure the functionality of the network. So we used the length of the network as the output of the stage 1. The results shown in Table 5 indicate that in Phase 1, several water companies did not perform their operations and maintenance activities by minimum costs. Most of the water companies were identified as cost-inefficient under Phase 1. Based on the results, we observe that in 2020 only 1 out of 21 production units was technically efficient, namely Vodohospodárská společnost Olomouc (VSO). It is followed by Pražské vodovody a kanalizace (PVK) (99.9%), Severomoravské vodovody a kanalizace Ostrava (SVKO) (99.9%), and Severočeské vodovody a kanalizace (SVK) (97.65%), which are very close to full technical efficiency. Other entities achieved a technical efficiency of 76.63% and less. This result suggests that most water companies should better allocate their resources by improving day-to-day operations, maintaining infrastructure and catching up with the most efficient companies.

In the second phase, companies use the water supply network to supply water, and therefore it represents the input of the 2nd phase. The volume of supplied drinking water and the number of customers connected to the public water supply are the outputs of the second phase. In this phase, we record up to 15 technically efficient companies during the year 2020. The Severomoravské vodovody a kanalizace Ostrava (SVKO), which was almost technically efficient production unit in the first phase, achieved surprisingly unfavorable result, and in the second phase it reached the efficiency of 30.79%.

Table 5 Technical efficiency of water companies in 2018–2020 assessed by two-stage DEA model

DMU 2020	Efficiency of the 1. phase	Efficiency of the 2. phase	Overall efficiency	Order
PVK	0.99998	1	0.99999	2
SVK	0.97654	1	0.98813	3
SVKO	0.99998	0.30799	0.65399	12
BVK	0.76633	1	0.86771	4
CEV	0.64068	1	0.78099	7
VAS	0.64832	1	0.78664	6
OVK	0.72385	1	0.83981	5
SCV	0.53739	1	0.69909	8
VPL	0.52660	1	0.68990	9
VKKV	0.50215	1	0.66857	11
KHP	0.41580	1	0.58737	13
VKH	0.51091	1	0.67629	10
VKMB	0.42342	0.46947	0.43712	17
VKB	0.40970	1	0.58126	14
VKP	0.43615	0.58729	0.48205	16
VKV	0.36030	0.22282	0.30312	21
VKK	0.35344	1	0.52229	15
VSR	0.27156	1	0.42712	18
VOS	0.26686	0.59209	0.33536	20

Table 5 (continuation)

DMU 2020	Efficiency of the 1. phase	Efficiency of the 2. phase	Overall efficiency	Order
VSB	0.24268	0.69961	0.36036	19
VSO	1	1	1	1
DMU 2019	**Efficiency of the 1. phase**	**Efficiency of the 2. phase**	**Overall efficiency**	**Order**
PVK	0.99998	1	0.99999	2
SVK	0.89861	1	0.94660	3
SVKO	1	0.2262	0.61310	21
BVK	0.72219	1	0.83869	7
CEV	0.61802	1	0.76392	10
VAS	0.64932	0.67555	0.65965	19
OVK	0.86103	1	0.92533	4
SCV	0.73847	1	0.84956	6
VPL	0.62442	1	0.76879	9
VKKV	0.68778	0.64752	0.67137	15
KHP	0.57315	1	0.72866	11
VKH	0.81036	0.42014	0.63569	20
VKMB	0.72888	0.56885	0.66141	18
VKB	0.76461	0.57250	0.68137	14
VKP	0.86160	0.44153	0.66718	16
VKV	0.66200	0.78743	0.71196	12
VKK	0.78047	0.82343	0.79930	8
VSR	0.54215	0.89340	0.66563	17
VOS	0.74675	1	0.85501	5
VSB	0.52121	1	0.68526	13
VSO	1	1	1	1
DMU 2018	**Efficiency of the 1. phase**	**Efficiency of the 2. phase**	**Overall efficiency**	**Order**
PVK	0.99999	1	1	1
SVK	0.79583	1	0.88631	4
SVKO	1	0.15721	0.5786	20
BVK	0.76699	1	0.86813	5
CEV	0.644	1	0.78346	8
VAS	0.67288	0.21533	0.48884	21
OVK	0.91392	1	0.95502	3
SCV	0.74777	1	0.85568	6
VPL	0.64733	1	0.78591	7
VKKV	0.75115	0.73261	0.7432	10
KHP	0.5805	1	0.73458	11
VKH	0.8535	0.53582	0.70721	14

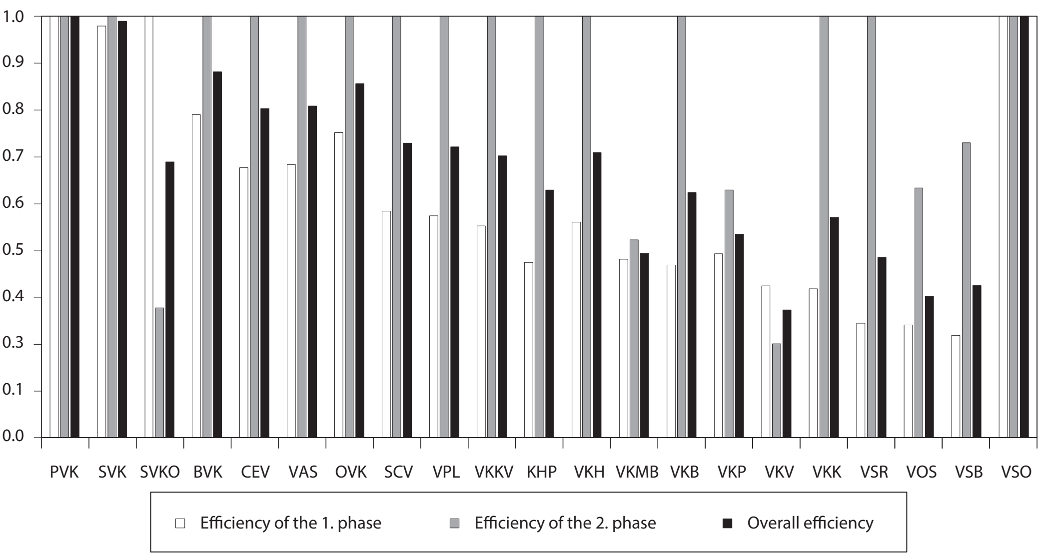
Table 5 (continuation)

DMU 2018	Efficiency of the 1. phase	Efficiency of the 2. phase	Overall efficiency	Order
VKMB	0.74387	0.5408	0.65725	16
VKB	0.81354	0.45802	0.65406	17
VKP	0.88052	0.34152	0.62814	19
VKV	0.6928	0.5783	0.64594	18
VKK	0.77986	0.64208	0.71949	13
VSR	0.58015	1	0.7343	12
VOS	0.77982	0.71869	0.75304	9
VSB	0.49577	1	0.66289	15
VSO	1	1	1	1

Note: Pražské vodovody a kanalizace (PVK), Severočeské vodovody a kanalizace (SVK), Severomoravské vodovody a kanalizace Ostrava (SVKO), Brněnské vodárny a kanalizace (BVK), ČEVAK (CEV), Vodárenská akciová společnost in Brno (VAS), Ostravské vodárny a kanalizace (OVK), Stredočeské vodárny (SCV), Vodárna Plzeň (VPL), Vodárny a kanalizace Karlovy Vary (VKKV), Královéhradecká provozní (KHP), Vodovody a kanalizace Hodonín (VKH), Vodovody a kanalizace Mladá Boleslav (VKMB), Vodovody a kanalizace Břeclav (VKB), Vodovody a kanalizace Přerov (VKP), Vodovody a kanalizace Vsetín (VKV), Vodovody a kanalizace Kroměříž (VKK), Vodohospodářská společnost Rokycany (VSR), Vodohospodářská a obchodní společnost (VOS), Vodohospodářská společnost Benešov (VSB), Vodohospodářská společnost Olomouc (VSO).
Source: Authors

As for the overall efficiency, we can also see the results in Table 5 together with the order of the analyzed subjects. Only one entity can be identified as an overall technically efficient production unit during all three analyzed years, namely Vodohospodárská společnost Olomouc (VSO). Pražské vodovody a kanalizace (PVK) is very close to full technical efficiency (99.9% in 2020, 2019, almost 100% in 2018), which ranks 2nd overall. In 2020 and 2019, Severočeské vodovody a kanalizace (SVK) was in third place (98.8% in 2020, 94.66% in 2019). In 2028, the third position belonged to Ostravské vodárny a kanalizace (OVK).

Figure 2 Technical efficiency of the water companies in Czech Republic in 2020

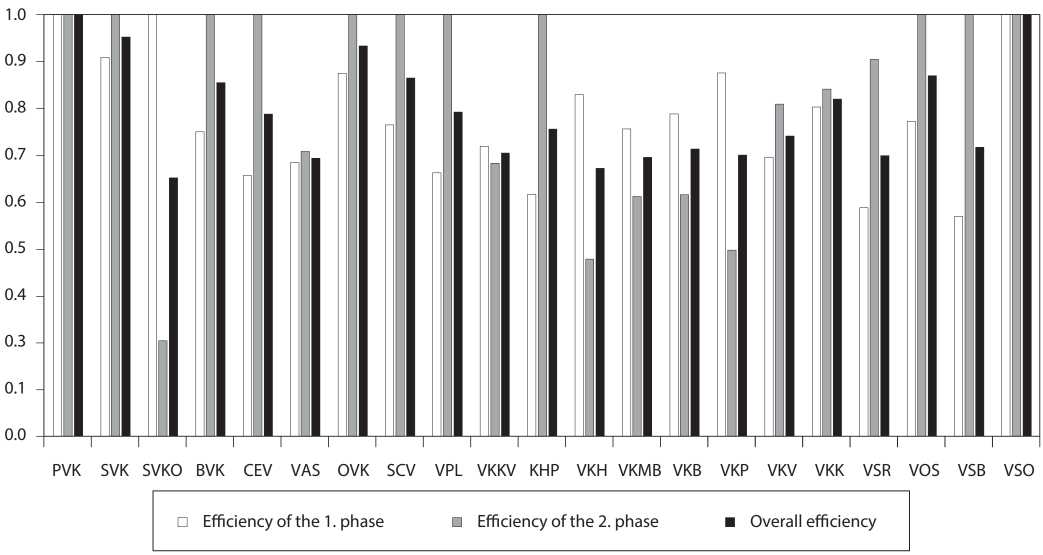


Source: Authors

Vodárenská akciová společnost (VAS), based in Brno, which provides services in the south of Moravia, Vysočina and part of the Pardubice region, recorded a significant increase in overall technical efficiency. While in 2018 it operated with the lowest technical efficiency of the assessed companies and ranked 21st (48.88%), in 2019 it ranked 19th (65.96%) and in 2020 it ranked 6th (78.66%).

Technical efficiency was calculated by each individual year separately, no data pooling was used. Figure 2 illustrates the ranking of water companies in the Czech Republic in 2020. The best result was achieved by the company Vodohospodárská společnost Olomouc (VSO), which was an efficient production unit in both phases of the process, and therefore also in overall efficiency. The VSO belongs to smaller water companies. It is worth to notice that the overall efficiency has almost been achieved by Pražské vodovody a kanalizace (PVK), i.e. the largest water company in the Czech Republic. Severočeské vodovody a kanalizace (SVK) is approaching the level of full technical efficiency as it is the third best production unit. The company Vodovody a kanalizace Vsetín (VKV) achieved the lowest efficiency score.

Figure 3 Technical efficiency of the water companies in Czech Republic in 2019

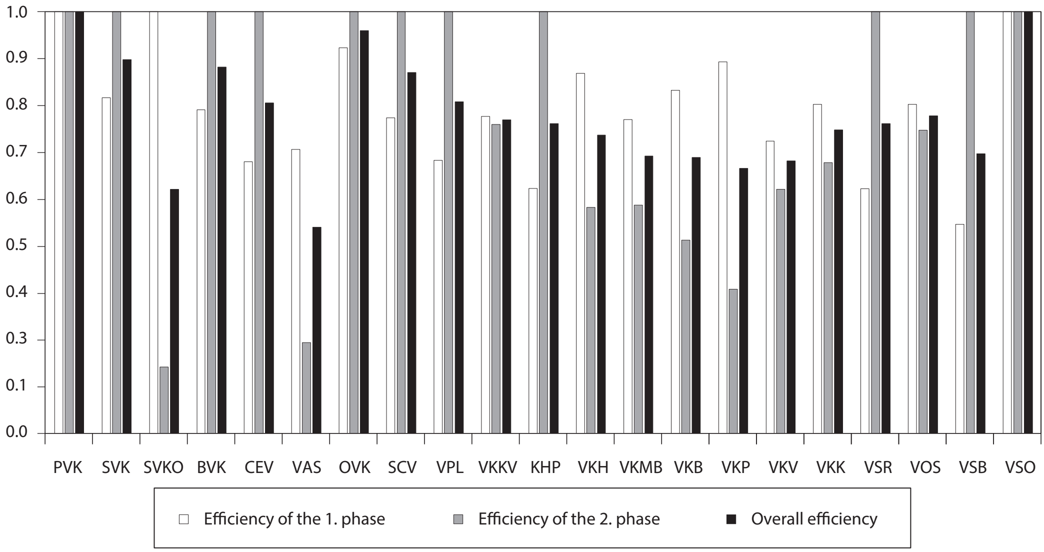


Source: Authors

Figure 3 shows the ranking of water companies from in the Czech Republic in 2019. The overall ranking of companies in terms of efficiency did not change significantly. Again, the Vodohospodářská společnost Olomouc (VSO) is the overall efficient unit, and we consider Pražské vodovody a kanalizace (PVK) and Severočeské vodovody a kanalizace (SVK) to be nearly efficient. The Severomoravské vodovody a kanalizace Ostrava (SVKO) is the least efficient production unit.

Figure 4 illustrates the ranking of water companies from in the Czech Republic in 2018. The best result was achieved by the company Vodohospodářská společnost Olomouc (VSO), which was an efficient production unit in both phases of the process, and therefore also in overall efficiency in all three analyzed years. Pražské vodovody a kanalizace (PVK) almost achieved overall efficiency, and Ostravské vodárny a kanalizace (OVK) took third place. The lowest efficiency score was achieved by Vodárenská akciová společnost (VAS).

Figure 4 Technical efficiency of the water companies in Czech Republic in 2018



Source: Authors

CONCLUSION

In conclusion, the importance of efficiency in the water industry cannot be overstated. It not only ensures the responsible use of a precious resource but also has wide-reaching implications for the environment, public health, economics, and overall sustainability. Therefore, continuous efforts to improve efficiency in the water sector are crucial for addressing the challenges of the 21st century.

The two-stage Network DEA model provides a thorough overview of the efficiency of individual process phases, which we consider important in complex production systems such as the water management system. Managers can thus observe the efficiency of individual phases as well as the overall efficiency within water management. Our findings show that water utilities should improve their cost performance by allocating their costs more efficiently and creating new practices that could reduce water supply costs and increase the volume of water supplied and the number of customers.

The results of our analysis can be interesting for policy makers in the water sector as well as for the management of individual investigated water companies operating in the Czech Republic. The results can also be an important benefit for regulatory authorities. In the Czech Republic, there is a clear absence of an independent central body that would have the competences of regulators in developed countries. The Authority could iniciate wide policies that are necessary in today´s economic and climate conditions. Is should introduce incentives that could lead to improved cost-effectiveness and efficiency in the provision of water management services. Findings at the level of individual stages of the production process can help the regulatory body to design policies based on incentives in the form of financial rewards.

We recommend to use the outputs of such an analysis in the determination of price tariffs for customers.

The information obtained as part of the analysis can lead to the improvement of the efficiency of water management in the Czech Republic, but also to the motivation of strategic planning aimed at increasing sustainability and resilience. Our future research will include the results of the technical efficiency of water management enterprises in the Czech Republic and Slovak Republic together.

ACKNOWLEDGEMENT

The research done in this paper is associated with the grant scheme VEGA 1/0442/22 New DEA models applicable for regulatory purposes in financial and network industries.

References

EAGRI. (2022). *eAGRI Portal* [online]. Prague: Ministry of Agriculture of the Czech Republic.

GLEICK, P. H. (1993). *Water in crisis.* Oxford University Press, New York. ISBN: 9780195076288

JABLONSKÝ, J., DLOUHÝ, M. (2015). *Modely hodnocení efektivnosti a alokace zdroju.* Prague: Profesional publishing. ISBN: 9788074311550

LIANG, X., LI, J., GUO, G,. LI, S., GONG, Q. (2001). Evaluation for water resource system efficiency and influencing factors in western China: A two-stage network DEA-Tobit model [online]. *Journal of cleaner production,* 328: 129674. <https://doi.org/10.1016/j.jclepro.2021.129674>.

LIU, J., FUKUSHIGE, M. (2019). Efficiency and pricing of water supply and sewerage services in Japan [online]. *Utilities policy*, 62: 957–1787. <https://doi.org/10.1016/j.jup.2019.100984>.

MOLINOS-SENANTE, M., MAZIOTIS, A. (2021). Benchmarking the efficiency of water and sewerage companies: Application of the stochastic non-parametric envelopment of data (stoned) method [online]. *Expert Systems With Applications,* 186: 957–4174. <https://doi.org/10.1016/j.eswa.2021.115711>.

SALAZAR-ADAMS, A. (2021). The efficiency of post-reform water utilitties in Mexico [online]. *Utilities policy*, 68: 101153. <https://doi.org/10.1016/j.jup.2020.101153>.

THANASSOULIS, E. (2000a). DEA and its use in the regulation of water companies [online]. *European Journal of Operational Research*, 127(1): 1–13. <https://doi.org/10.1016/S0377-2217(99)00436-1>.

THANASSOULIS, E. (2000b). The use of data envelopment analysis in the regulation of UK water utilities: Water distribution [online]. *European Journal of Operational Research*, 126(2): 436–453. <https://doi.org/10.1016/S0377-2217(99)00303-3>.

TONE, K., TSUTSUI, M. (2009). Network DEA: A slack-based measure approach [online]. *European journal of operational research*, 197(1): 243–252. <https://doi.org/10.1016/j.ejor.2008.05.027>. ISSN 0377-2217

ZHOU, X., LUO, R., YAO, L., CAO, S., WANG, S., LEV, B. (2018). Assessing integrated water use and wastewater treatment systems in China: A mixed network structure two-stage SBM DEA model [online]. *Journal of Cleaner Production*, 185: 533–546. <https://doi.org/10.1016/j.jclepro.2018.02.278>.