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Estimating environmental benefits of wastewater treatment in Slovakia

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Abstract

Proper wastewater management contributes to public health, provides environmental benefits and can be economically profitable. In Slovakia, the ratio of population connected to public sewerage is slowly increasing as new wastewater treatment plants are being constructed but is still low in international comparison. The aim of this study is to estimate environmental benefits of wastewater treatment in Slovakia. A model approach uses a sample of 57 medium-sized Slovak wastewater treatment plants to estimate the environmental benefits of wastewater treatment. Treatment of all wastewater released into the rivers and other surface waters brings total environmental benefits of 1.96 billion euros per year.

Authors

Veronika Antalová veronika.antalova@enviro.gov.sk
Stella Slučiaková stella.sluciakova@enviro.gov.sk
Martin Haluš martin.halus@enviro.gov.sk

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Introduction

Water is an important natural resource and it is not possible neither for humans nor for the economy to substitute it. The global climate change is transforming water scarcity into an even more widespread problem. One fifth of the world's population, or 1.2 billion people, live in areas of water scarcity, and this number is projected to rise to 3 billion by 2025, as water stress and population increase (United Nations Environmental Program, 2010). The challenge of a sustainable and safe water supply is no longer just a problem of the developing world but continues to gain prominence within the developed and seemingly water-rich countries. A responsible water management has therefore become an inseparable part of the environmental policy in Slovakia as well.

Wastewater has historically been considered a great threat and a problem. Untreated wastewater would cause severe illnesses, premature death and damage to affected water ecosystems and the environment. However, wastewater has begun to be seen not only as waste, but also as a resource (United Nations World Water Assessment Programme, 2017). The use of treated water is becoming more widespread for the purposes that don't require drinking water quality, such as irrigation or some industrial uses. Moreover, the agricultural use of the treated water still containing some levels of nutrients reduces the need to use chemical fertiliser. This results in a reliable source of water and an improved food security.

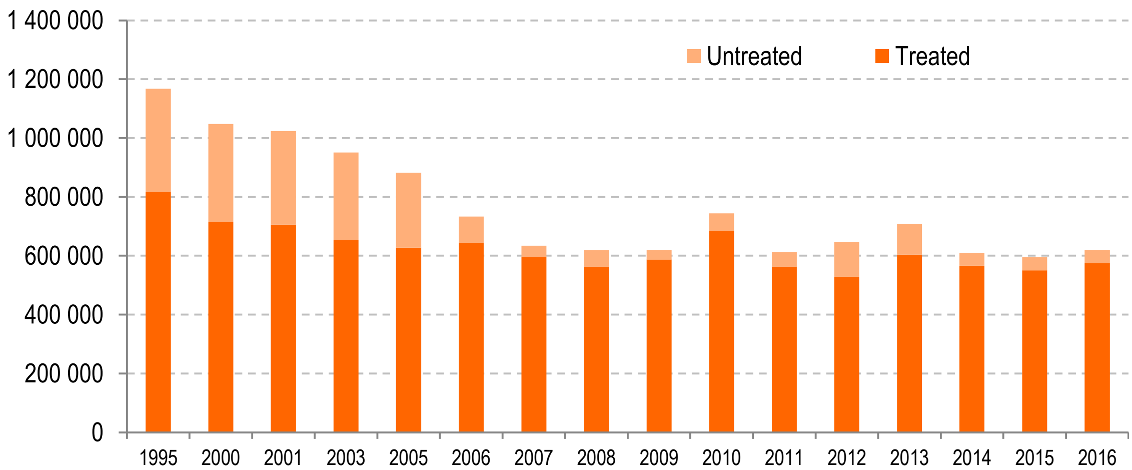
Reliable data are necessary for an effective wastewater management. The estimation of environmental costs that are avoided through the process of treating the wastewater is an important part of the decision making process. In this paper, the avoided environmental costs are considered to be the environmental benefits of the wastewater treatment and a shadow price methodology is applied on empirical data from the Slovak urban wastewater treatment plants. By means of an applied model we estimate that the society would be willing to pay 1.96 billion euros to remove pollutants from the environment, had the wastewater not been treated. This value can be considered a lower-bound estimate, since only certain pollutants are included. Total damage caused by the wastewater would most certainly be much higher.

1 Overview of wastewater management in Slovakia

Wastewater has been affected in quality terms, meaning it might include different pollutants, have a different temperature or other altered characteristics. Urban wastewater considered in this analysis is collected within the sewer systems from households, part of industry and various institutions and transferred into the wastewater treatment plant. It consists of different flows which mix in the sewer system and are then treated together, including commercial and agricultural wastewater, surface runoff and rainwater. The wastewater consists of around 99.9 % water and only 0.01 % of substances that need to be removed through the treatment processes, including organic matter, microorganisms and inorganic compounds.

Release of wastewater flows into the environment still influences the quality of surface waters, even though the amount released into surface water has fallen to almost half of the value compared to 1995. The proportion as well as the absolute value of released untreated water has been decreasing over time as well. However, this figure is self-reported by the polluters and the proportion of the untreated water could be higher. New wastewater treatment plants are being incorporated into the system every year (Water Research Institute, 2017).

Figure 1: Amounts of wastewater released into surface waters in thousands of m^3



Source: Slovak Hydrometeorological Institute

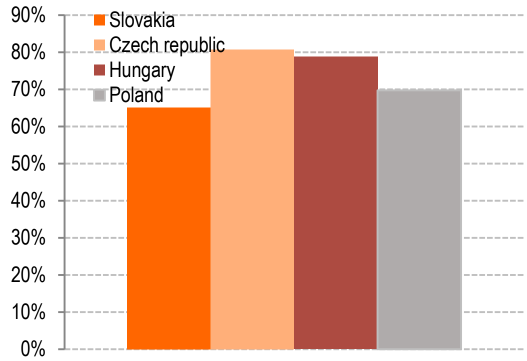
As laid down in the EU Water Framework Directive (The European Communities, 2000) a favourable ecological and chemical status of all waters is to be achieved by 2027 at the latest. About 65 % of the Slovak surface waters is currently in a favourable ecological status and almost all of them are in a good chemical status (European Commission, 2017). The pollution remaining in the waters with bad status is caused by organic materials, nutrients and hazardous substances. These pollutants are removed to a great extent through the wastewater treatment process which, therefore, helps to achieve a better overall quality of waters.

Drinking water is in most cases safe, but the pollution from wastewater still influences some sources. The current state of implementation of the Water Framework Directive is in Slovakia generally good. Public groundwater sources of drinking water are less susceptible to pollution than private wells. Up to 85 % of water from non-public drinking water sources, such as private wells does not meet the hygienic standards (Public Health Authority of the Slovak Republic, 2009), most often due to the presence of faecal pollution, nitrates and iron. The reason could be insufficient depth of the wells and the leakage of sewage water.

The amount of pollution in wastewater is decreasing. Between 1995 and 2015, the number of pollutants decreased by almost 80 %, due to more modern wastewater treatment plants and more efficient purification processes (Slovak environment agency, 2015) along with the decline in industrial production. The contamination of urban wastewater flows with industrial wastewater used to contribute to contamination of the sludge which resulted in a partial inapplicability on the agricultural soil (Ministry of Environment of the Slovak republic, 2004). This problem was solved by stricter regulation. However, abnormal levels of sludge contamination are still sometimes reported (Ministry of Environment of the Slovak republic; Water Research Institute, 2016) due to non-compliance of smaller industries.

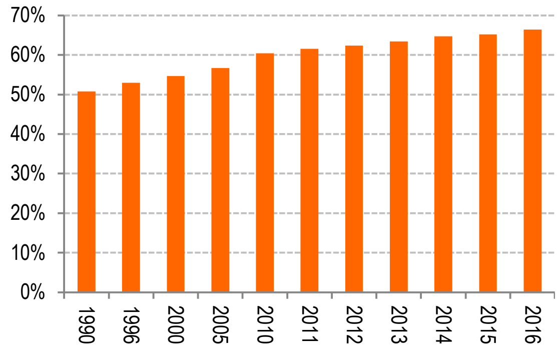
The share of population connected to the public sewage systems has been increasing but it still lags behind our neighbours. The increase in the connection rate is a direct result of an increased EU funding after the accession in 2004. However, the connection rate in Slovakia is still low in international comparison. Furthermore, nearly 28 % of the population lives in agglomerations of up to 2000 population equivalents with below-average connection rate which are not eligible for the EU funding. Only 25.8 % of people living in the small municipalities (Water Research Institute, 2017) are connected to public.

Figure 2: Public sewage system connection rate, 2015 (%)



Source: Bureaus of Statistic of respective countries, Eurostat

Figure 3: Population connection rate to public sewage systems in Slovakia (%)



Source: Slovak Bureau of Statistics, Water Research Institute

According to the public sewerage act, every owner of the property in which waste water is generated must be connected to the public sewer system[1]. However, in the short term perspective there are still people who do not want to or cannot connect to the public sewerage. They either have a valid permit to treat the water privately or discharge the wastewater in an illegal way. Based on the currently collected data, it is not possible to estimate how big these groups are nor how much environmental damage this incorrect disposal is causing.

More explicit data is needed to conduct thorough cost-benefit analyses of the wastewater treatment investments. The costs of such treatment are well known, the benefits are more difficult to estimate and might seem less tangible. But the removal of pollutants during the wastewater treatment process is associated with various social benefits. Economic estimation of these benefits in the Slovak context would allow for more informed decision making. Further chapters will estimate and describe environmental benefits of wastewater treatment.

[1] According to the Act No. 442/2012 Coll. on public water supply and public sewerage and on amendment to Act No. 276/2001 Coll. on regulation of network industries, the owner of the building or land can be exempted if he has a permission to treat generated wastewater differently, for example in a self-operated domestic treatment plant. The data on amounts treated within these special permissions is not centrally collected, which is a serious obstacle when trying to ascertain the amounts of wastewater which are not treated in any way and contribute the most to the wastewater pollution.

2 Wastewater treatment makes sense

Removal of pollutants from wastewater produces cleaner water and has several indirect positive effects. First of all, the improved access to drinking water bears health benefits such as reduction of number of people affected by water-related diseases and decrease in the number of deaths. Secondly, through using by-products of the treatment process as new material or new economic activities induced by cleaner downstream waters, additional economic profits are created. Thirdly, environmental benefits include safer and more stable aquatic ecosystems, lower use of chemical fertilisers and reduced amount of wastewater released into the environment without any treatment. And lastly, wastewater treatment provides a sustainable solution to some aspects of the water scarcity problem.

By releasing the wastewater into the surface and consequently into water streams, the pollutants and pathogens enter the water cycle and spread to drinking and recreational waters. Reduction of pathogens and pollutants in the water cycle decreases the number of people affected by water-borne illnesses. Contaminated water can transmit diseases such as diarrhoea, cholera, dysentery, typhoid, and polio. Around 88 % of all diarrhoeal incidents globally are connected to poor hygiene and drinking of unsafe water (United Nations Environmental Program, 2010). Contaminated drinking water is estimated to cause 502,000 diarrhoeal deaths each year (World Health Organisation, 2017). There have been only a few outbreaks of water-borne diseases reported in the previous years in Europe, but the figure tends to be underreported (European Centre for Disease Prevention and Control, 2009).

Monetary value of these health benefits can be estimated directly through healthcare costs related to the illnesses or indirectly through other indicators. Direct healthcare costs of water-borne diseases have been estimated in the United States (Collier, et al., 2012) based on the costs of hospitalizations and visit costs of patients with ten water-borne diseases. Five primarily water-borne diseases accounted for 970 million USD per year and at least a part of 860 million USD for the other five diseases can be attributed to the water-borne transmission.

Another way of estimating health benefits is the productivity loss suffered due to illness. Potential lifetime earnings lost due to the premature death are broadly used for illnesses where the risk of death is higher (Bradley, et al., 2008). Productivity losses when the sickness was mostly treatable were calculated in relation to the water-borne Cryptosporidium outbreak in Wisconsin in 1993 (Corso, et al., 2003). The outbreak was a result of an ineffective filtration process in one of the two municipal wastewater treatment plants and resulted in more than 400,000 people becoming ill. Estimated productivity costs due to the outbreak were 64.6 million USD, in addition to the 31.7 million of medical costs. The data used for this analysis was primarily the medical and financial records of the local hospitals and a survey conducted among patients and their caregivers.

Economic benefits of waste water treatment relate to either the direct use of by-products such as sludge and biogas, or indirectly tourism and recreation in cleaner rivers and lakes. The wastewater sludge as a by-product of wastewater treatment can create additional economic value as a fertiliser in agriculture or as a fuel for incineration. Dried sludge can be disposed through incineration to create heat and energy reducing the need for possibly “dirtier” sources of energy. Most of the sludge created in the Slovak urban wastewater treatment plants is composted and used later on as a nutritious fertiliser. Almost one third of the wastewater sludge is incinerated and none is directly applied to agricultural land. In 2015, 56,240 tonnes of sludge were created in the Slovak urban wastewater treatment plants (Eurostat, 2017).

Capture of biogas during the process of sludge stabilisation has several positive implications. It consists mostly of methane and carbon dioxide, which are both significant greenhouse gases, but no less important is the economic motivation. Biogas can be burned to produce heat to support the treatment processes or as a fuel for cogeneration power plants to create electricity. In Slovakia, it is mostly used to produce electricity and heat, but only the biggest wastewater treatment plants collect biogas.

Recreational benefits are an important part of the water pollution control (Tietenberg & Lewis, 2016). Natural and recreational fisheries rely heavily on the conditions and quality of the water. The reproductive potential of fish is decreasing with pollution (Cowx, 2015) and it is therefore higher in cleaner rivers and lakes. Commercial fisheries may be positively affected as well. One of the first estimations of recreational value of improved water quality was done in the Rocky Mountain National Park in Colorado (Walsh, et al., 1978). Willingness to pay for the higher water quality was assessed through survey with six photos of different water quality levels and estimated that the visitors were willing to pay extra 1 %, or $0.06, to the daily recreation fee to avoid a unit decrease in water quality. Prices of waterfront properties increased with the water quality as well and the travellers were be willing to travel longer distances to reach the destination.

Nutrients, such as nitrogen, phosphorus or potassium, which are eminently prevalent in the wastewater cause eutrophication[2] and excess plant growth. They are connected with proliferation of algal blooms and an undesirable disturbance to the species composition and quantity in the water (European Environment Agency, 2012). The risk of eutrophication is still widespread across Europe, even though it is expected to decline in the future (European Environment Agency, 2016). Freshwater ecosystems are important for global biodiversity and provide essential ecosystem services, but are vulnerable to any changes in environment (Angeler, et al., 2014). Wastewater changes the composition and quality of waters and its treatment therefore helps to maintain the equilibrium.

Wastewater might be a key to solve the global water crisis. By 2025, half of the world's population will be living in water-stressed areas (World Health Organisation, 2017). Repeated use of water is already common practice in some areas of the world and water scarcity will due to climate change become a problem even in currently water-rich countries, such as Slovakia. The city of San Diego in southern California is already planning to treat its wastewater to meet the drinking water quality criteria and provide one third of its drinking water needs by 2035 (The City of San Diego, 2017). The monetary value of wastewater reuse has been researched recently in Tel Aviv (Garcia & Pargament, 2015). Use of wastewater for irrigation purposes has been estimated to contribute to social value by approximately 4.83 million USD per year. This includes agricultural fertilisation, improvements in crop composition, the price of the water that would have to be used in agriculture and parks and environmental impacts of nitrate and phosphorus.

The value of improved water quality has been addressed as well through willingness to pay methods. Hill interviewed 450 households within the Barwon-Darling River area after a cyanobacterial bloom spread there (Hill, 1994). Based on the results, people were willing to add 20 AUD per household to achieve an improved water quality in the river. Aggregated, this would mean a one off investment of 26 million AUD to improve the water quality in the area.

[2] Eutrophication is the process of enrichment of water by nutrients, acceleration in growth of algae and higher forms of plant life and depletion of oxygen resulting vegetation and species composition alterations within the affected area.

3 Estimating environmental benefits of wastewater treatment in Slovakia

The economic value of wastewater treatment is often not known. However, valuation of these non-marketed benefits is necessary to design efficient environmental policies. The benefits can be estimated by various methods. Among the most common ones are willingness-to-pay, stated and revealed preference methods.

The methodology applied in this paper uses a shadow price estimation, where the monetary value of the environmental benefits of wastewater treatment is revealed through the costs that wastewater treatment plants (or society) are willing to bear to achieve a certain level of treated water quality. The model approach follows studies by Färe (Färe, et al., 2002) and improves the model used by Hernandéz-Sancho (Hernández-Sancho, et al., 2010). Methodology used for the economic valuation is based on the estimation of shadow prices for the pollutants removed in a treatment process. Total estimated value represents the cost avoided by undischarged pollution.

Theoretical framework

The estimation of shadow price takes into account revenue function and distance function for each individual wastewater treatment plant. The plant aims to maximise its revenue function through maximisation of the amount of treated water and minimisation of the undesirable outputs with fixed costs. The distance function reflects the efficiency of each plant in terms of maximising the revenue function. The shadow price is then calculated using the effectivity, reference price of the treated water and amounts of desirable and undesirable outputs. The shadow price can be interpreted (Zhou, et al., 2014) as the opportunity cost of abating one additional unit of undesirable output in terms of the loss of desirable output.

Pricing model is based on directional output distance function that seeks to reduce undesirable outputs and maximise desirable outputs simultaneously, using given inputs. In our particular application, the process of wastewater treatment produces only one desirable output which is treated water, and 4 undesirable outputs: *nitrogen* (N), *phosphorus* (P), *suspended solids* (SS*)* and organic pollution measured as *chemical oxygen demand* (COD). The inputs needed to carry out the treatment are *energy, staff, reagents and maintenance* and *others.*

The distance function represents the technology and bears axiomatic assumptions with properties of the output set *P(x)* (Färe, et al., 2002). Output set denotes the set of desirable and undesirable outputs that can be produced from the input vector x and is defined as:

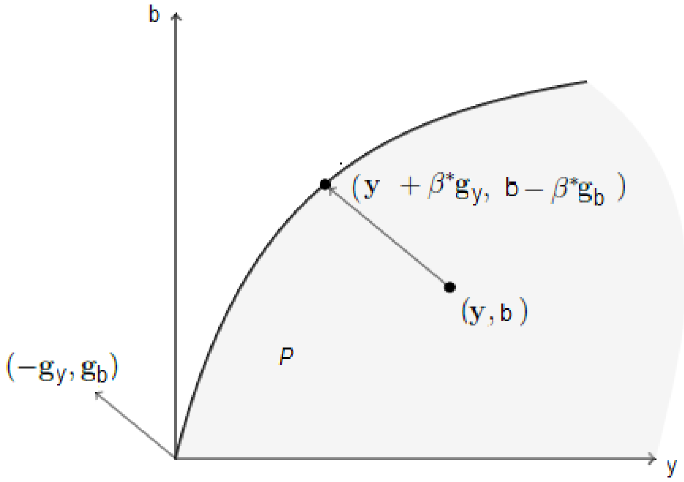
$$P(x) = \{(y, b): x \text{ can produce } (y, b)\}$$

The directional output distance function is formally defined as:

$$D(x, y, b; g) = \max_{\beta} \{\beta: (y + \beta * g_y, b - \beta * g_b) \in P(x)\}$$

i.e., it is the largest feasible value of the projection of *(y, b)* onto the boundary of *P(x)* in the direction g, where y are desirable and b are undesirable outputs. In other words, the computed value β provides maximum expansion of marketable outputs and reduction of pollutants if a firm operates efficiently given the directional vector *g*. The vector $g = (g_y, g_b)$ specifies the direction in which an output vector *(y, b)* is projected onto the frontier or boundary of output set at the point $(y + \beta^* g_y, b - \beta^* g_b) \in P(x)$. Figure 7 provides an illustration of the case of one desirable output y and one undesirable output b. In our estimation of the distance function we set g= (1,-1), which is consistent with requirement of reduction of undesirable outputs.

Figure 4: The directional output distance function



Source: IEP

The directional output distance function varies between 0 and 1. It takes the value of zero for technically efficient output vectors on the frontier, while positive values imply inefficiency. The higher the value, the more inefficient is the output vector and so the firm.

The function can be specified in several functional forms. For the purpose of this analysis, we have chosen the parametric quadratic functional form, which satisfies required properties (Färe, et al., 2002). Applied to our case with *k* units of wastewater treatment plants, one desirable output *y*, 4 undesirable outputs *b* and 4 inputs *x*, the formula is:

$$D(x^k, y^k, b^k; 1, -1)$$
$$= \alpha_0 + \sum_{n=1}^{4} \alpha_n x_n^k + \beta_1 y^k + \sum_{l=1}^{4} \gamma_l b_l^k + \frac{1}{2}\sum_{n=1}^{4}\sum_{n'=1}^{4} \alpha_{nn'} x_n^k x_{n'}^k + \frac{1}{2}\beta_2 y^k y^k$$
$$+ \frac{1}{2}\sum_{l=1}^{4}\sum_{l'=1}^{4} \gamma_{ll'} b_l^k b_{l'}^k + \frac{1}{2}\sum_{n=1}^{4} \mu_n x_n^k y^k + \frac{1}{2}\sum_{n=1}^{4}\sum_{l=1}^{4} \delta_{nl} x_n^k b_l^k + \frac{1}{2}\sum_{l=1}^{4} \rho_l b_l^k y^k$$

We estimate the parameters of the distance function by solving the following minimization problem:

$$\min \sum_{k=1}^{57} \left(D(x^k, y^k, b^k; 1, -1) - 0 \right)$$
$$s.t.\ D(x^k, y^k, b^k; 1, -1) \geq 0, k = 1, \dots, 57$$
$$\frac{\partial D(x^k, y^k, b^k; 1, -1)}{\partial b_l} \geq 0, l = 1, \dots, 4, k = 1, \dots, 57$$
$$\frac{\partial D(x^k, y^k, b^k; 1, -1)}{\partial y} \geq 0, k = 1, \dots, 57$$
$$\beta_1 - \sum_{l=1}^{4} \gamma_l = -1,\ \beta_2 = \sum_{l=1}^{4} \rho_l,\ \rho_l = \sum_{l=1}^{4} \gamma_{ll'},\ \mu_n = \sum_{l=1}^{4} \delta_{nl}$$
$$\alpha_{nn'} = \alpha_{n'n}, \qquad \gamma_{ll'} = \gamma_{l'l}$$

objective function minimizes the sum of deviations of the estimated distance functions for every unit from the efficient value of zero, i.e. their frontier. Constraint set ensures assumptions are fulfilled. To solve the minimization problem we used GAMS software with the CPLEX solver.

Data

The sample used in this analysis consists of 57 wastewater treatment plants in the Slovak republic (Table 1). Statistical information has been supplied by each plant for the year 2016. We considered the plants with the volume of wastewater treated that varies between 1 and 12 million m^3 per year. Given the numerical size of outputs and inputs reported, we normalized the data by dividing each output and input by its mean value before estimating the model to prevent convergence problems.

Table 1: Description of the sample

			Average	Standard deviation	Max	Min
Inputs (€/year)	Energy	x_1	139810.51	101309.15	639042	51597.89
	Staff	x_2	189894.39	88897.73	503896.36	62886.85
	Reagents+	x_3	113694.36	111957.47	554145	4207.36
	Others	x_4	526725.19	415946.17	2252756	38236.06
Desirable output (m^3/year)	Treated water	y	2851831.89	2293168.61	12233360	944685
Undesirable outputs (kg/year)	Nitrogen	b_1	90718.49	91574.33	539452	14997.2
	Phosphorus	b_2	16421.92	19492.83	85710	347
	SS	b_3	647201.08	809349.25	4806722	123076.3
	COD	b_4	1254598.57	1464031.25	9870639	52200

Source: IEP

Model results

The estimates of parameters of directional output distance function are provided in the Annex 1. The values of the distance functions give us the technical inefficiency estimates for each plant (Annex 2). It is important to note that the value of inefficiency does not give us the information about economic management of the plant. The plant is not able to decide about the amount of pollutants that occurs in the coming water, it can only decide about the amount of pollutants removed to meet the limits of pollutants in treated water.

The mean value of efficiency is 0.109, which means that, at the fixed costs, the amount of treated water could be on average expanded by 309 999 m^3 per year and the amount of all pollutants could be contracted by 218 375 kg per year simultaneously. It implies quite high level of efficiency of wastewater treatment plants in Slovakia.

Shadow pricing of undesirable outputs

Using the values of directional output distance function we can estimate the marginal abatement costs of each pollutant per plant (Färe, et al., 2002). As we consider fixed costs, each plant can maximize its revenue not profit. The revenue function of a plant may be derived as follows:

$$R(x,p,q) = \max_{y,b}\{p_y y - qb: D(x,y,b;1,-1) \geq 0\},$$

where p_y is the price of the desirable output and q marks prices of undesirable outputs. Condition for the distance function ensures feasibility, i.e. efficiency of 100% cannot be exceeded. In our case, p_y is the price of treated water which is marketable and the price q is a vector of shadow prices of the five pollutants.

Forming the Lagrangian form of revenue function and taking the first order conditions yields to find shadow prices. Assuming that the price of the desirable output, the treated water, is known and coincides with its shadow price, the absolute shadow prices of undesirable outputs are given by:

$$q_l = -p_y \frac{\partial D(x,y,b;1,-1)/\partial b}{\partial D(x,y,b;1,-1)/\partial y}, l = 1, \dots, 4$$

The minus sign in the equation ensures shadow prices to be negative to reflect the environmental damage avoided during the treatment process. Using our parametrization of distance function the equation of the shadow prices for each pollutant for every plant becomes:

$$q_l^k = -p_y \frac{\gamma_l + \sum_{l'=1}^{4} \gamma_{ll'} + \sum_{n=1}^{4} \delta_{nl} x_n^k + \rho_l y^k}{\beta_1 + \beta_2 y^k + \sum_{n=1}^{4} \mu_n x_n^k + \sum_{l=1}^{4} \rho_l b_l^k}, l = 1, \dots, 4, k = 1, \dots, 60$$

Table 2 shows the average shadow prices of four undesirable outputs. We have to inflate the ratio of derivatives of distance function by multiplying by the mean value of y to mean value of b to get original dimensions of data. It can be seen that the main environmental benefits from treatment are the elimination of *phosphorus and nitrogen.*

Table 2: Average shadow prices for the undesirable outputs - pollutants (€/kg)

Reference price of water (€/m3)	Shadow prices for undesirable outputs (€/kg)			
	N	P	SS	COD
0.991	-31.942	-82.433	-10.706	-2.277

Source: IEP

Considering the volume of pollutant removal in the treatment process within our sample and the shadow prices of pollutants, we can calculate the value of overall environmental benefits resulting from treatment of wastewater per year or per cubic meter of treated water. The biggest proportion of environmental benefits (49%) comes from the removal of the *suspended solids* and the *chemical oxygen demand.* Even though, *phosphorus* has high shadow price, it contributes to the value of benefit by only 10% because the volume removed in the treatment process is relatively low. The overall environmental benefits of the treatment stands at 4,922 euros per cubic meter.

Table 3: Environmental benefit of treatment in €/ year and €/m3 within the sample

Pollutants	Pollutant removal (kg/year)	Environmental value pollution (million €/year)	Environmental value pollution (€/m3)	%
N	5 170 953.8	165.17	1.016	21
P	936 049.5	77.16	0.475	10
SS	36 890 461.5	394.95	2.430	49
COD	71 512 118.6	162.83	1.002	20
Total		800.11	4.922	

Source: IEP

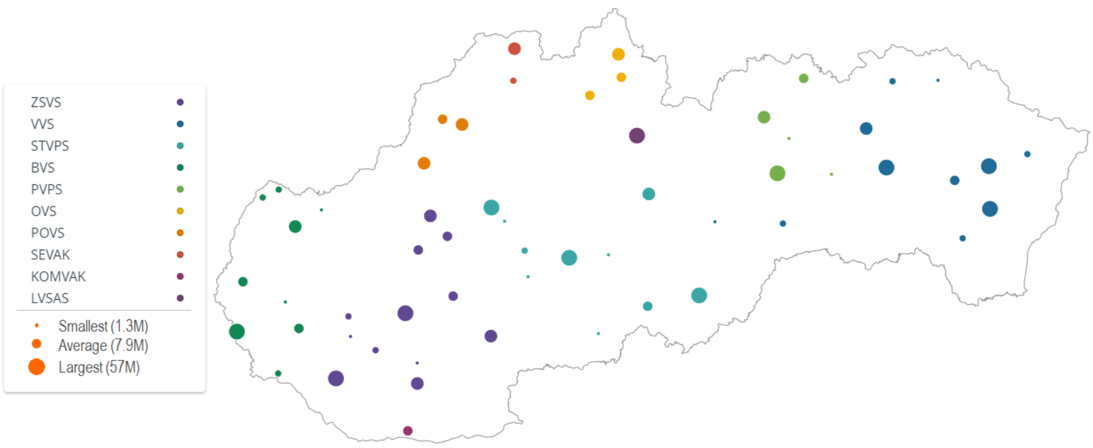
We introduced the results of the economic valuation study by Hernandéz-Sancho (Hernández-Sancho, et al., 2010). This study was conducted on 43 wastewater treatment plants located in the Spanish region of Valencia with the same range of the volume of wastewater treated as we considered in our case. Comparing the Slovak and Spanish data we see that the average values of energy, staff, reagents and maintenance are quite similar, while the average value of Others (e.g. amortization of long term assets) is five times higher for Slovak plants. Comparing values of outputs, *nitrogen* and *phosphorus* are similar, but values for *suspended solids* and *the chemical oxygen demand* are half as opposed to Spanish data. Also the average amount of treated water is lower in Slovak plants. These significant differences in data could cause the considerable differences in results of shadow prices. While the shadow prices for *nitrogen* and *phosphorus* are lower in our model, *SS* and *COD* are much higher than in Spanish study.

The other reason for inconsistency in results is a different form of distance function. We considered the parametric quadratic functional form of distance function which we believe to reflect the relationship better, while in Spanish study they used the translog (transcendental logarithmic) function. Furthermore, our model didn't include the biological oxygen demand even though it was included in the Hernandéz-Sancho's study, since biological oxygen demand and chemical oxygen demand measure the same pollution through different means. Incorporation of both indicators would result in double counting of this pollution.

Results and policy implications

Environmental benefits of treating the wastewater released into surface waters in Slovakia in 2016 are estimated to be 1.96 billion euros. This amount was calculated by multiplying the environmental benefits per cubic metre by the amount of domestic wastewater released into surface waters provided by Slovak Hydrometeorological Institute. It represents a lower bound estimate of costs to remove the pollution from the environment, had the wastewater not been treated. It would have to be invested in cleaning and reconstruction programmes, such as removal of nutrients to stop eutrophication of water bodies or saving the water organisms and ecosystems. There are however many other polluting substances being removed from the wastewater throughout the process that would further increase the benefits, had they been included.

Figure 5: Estimated benefits (size of the dot) of each wastewater treatment plant according to the firm (colour of the dot)



Source: IEP

Health benefits are not considered within this analysis. Wastewater treatment significantly decreases the number of people infected by water-related diseases and saves premature deaths. It was not within the scope of this analysis to estimate the monetary value of improved health level. The overall benefits of wastewater treatment would therefore be even higher. The quality of water has a positive impact on the local economy as well, both in terms of creating jobs in tourism, fisheries or agriculture and employing locals at wastewater treatment plants. Moreover, the some of the treatment plants could generate energy and reduce the country's dependency on imported fossil fuels.

In the future, possible implications of these results may be in cost-benefits analyses of wastewater treatment investment projects. While some of the partial data, such as the efficiency of removal of pollutants, is already considered, others might provide different perspective. The environmental benefits included in this analysis don't have a direct market price and hasn't been considered in the financial sense in any cost-benefit analysis. This led mostly to the underestimation of the total benefits of the wastewater treatment.

Annex 1: Parameter estimates of distance function

α_0	0.144	α_{24}	0.234	μ_3	0.073	δ_{44}	-0.073
α_1	0.248	α_{33}	0.119	μ_4	-0.118	ρ_1	-0.159
α_2	0.056	α_{34}	0.055	δ_{11}	0.343	ρ_2	-0.063
α_3	-0.227	α_{44}	-0.153	δ_{12}	0.209	ρ_3	0.036
α_4	-0.276	β_2	-0.195	δ_{13}	-0.381	ρ_4	-0.009
β_1	-0.451	γ_{11}	-0.081	δ_{14}	0.114	ρ_1	-0.073
γ_1	0.335	γ_{12}	-0.038	δ_{21}	-0.104		
γ_2	-0.024	γ_{13}	-0.05	δ_{22}	0.024		
γ_3	0.135	γ_{14}	0.009	δ_{23}	0.33		
γ_4	0.104	γ_{22}	0.004	δ_{24}	0.039		
γ_5	-0.241	γ_{23}	-0.047	δ_{31}	0.027		
α_{11}	-0.895	γ_{24}	0.018	δ_{32}	0.059		
α_{12}	-0.386	γ_{33}	0.177	δ_{33}	-0.009		
α_{13}	0.388	γ_{34}	-0.044	δ_{34}	-0.004		
α_{14}	-0.098	γ_{44}	0.009	δ_{41}	-0.072		
α_{22}	0.232	$\mu 1$	0.285	δ_{42}	-0.049		
α_{23}	0.144	$\mu 2$	0.29	δ_{43}	0.076		

Source: IEP

Annex 2: Estimates of inefficiency of each plant

Považská Bystrica	0.161	Dolný Kubín	0.096
Púchov	0.14	Nižná	0.045
Dubnica nad Váhom	0.54	Námestovo	0
Liptovský Mikuláš	0	Bardejov	0
Brezno	0.255	Humenné	0
Lučenec	0	Snina	0.048
Handlová	0.054	Michalovce	0.529
Prievidza	0.195	Prešov - Kendice	1.084
Rimavská Sobota	0.489	Sabinov	0.122
Veľký Krtíš	0.061	Rožňava	0
Detva	0	Revúca	0
Zvolen	0	Svidník	0.019
Banská Štiavnica	0.022	Trebišov	0
Žiar nad Hronom	0.003	Vranov – Lomnica	0.004
Spišská Nová Ves	0	Čadca	0.076
Kežmarok	0.113	Kysucké Nové Mesto	0.135
Stará Ľubovňa	0.078	Nitra	0
Levoča	0.113	Zlaté Moravce	0.281
Krompachy	0.008	Dunajská Streda – Kútniky	0
Devínska Nová Ves	0	Galanta	0
Modra	0.129	Sereď	0
Senec	0.449	Šaľa	0
Hamuliakovo	0	Levice	0
Malacky	0	Nové Zámky	0.038
Myjava	0.03	Šurany	0
Senica	0.165	Bánovce nad Bebravou	0.581
Holíč	0.021	Partizánske	0
Skalica	0	Topoľčany	0.112
Komárno	0	**Average**	**0.109**

Source: IEP

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