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Cost comparison of wastewater treatment in Danubian countries

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ABSTRACT

This paper investigates the costs of wastewater treatment (including sludge management) within the Danube catchment countries A, CZ, SK, HU, SL, RO, BG and UA. TK is considered as well. Additionally, the paper compares the total costs of wastewater management (including sewerage) with the incomes in the different countries. The annual costs of wastewater treatment in Austria are about 30 €/p.e. y for large plants with nitrogen and phosphorus removal. In low income countries of the Danube and Black Sea catchment areas they are at a maximum 30% lower than in Austria. However, the incomes in countries like Bulgaria, Romania or Ukraine are 85% to 90% lower. The total annual costs for wastewater management (sewer development plus treatment) amount at least to 90€/p.e. y. Considering the level of income in those countries, financing of wastewater management completely by charges of the population equivalents connected is not feasible. Therefore other approaches for financing wastewater treatment are required.

Key words | affordability, Black Sea catchment, cost calculations, wastewater treatment

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INTRODUCTION

Decreased nutrient discharges from the Danube have led to a significant improvement of the Western Black Sea ecosystem. As the decrease is partly due to the economic breakdown in the former communistic countries, economic development has to go along with proper wastewater management and best agricultural practice (Kroiss *et al.* 2006).

Within the Danube countries the status of wastewater management differs considerably. Differences exist in (1) the degree of population supplied with sewerage, (2) the part of wastewater collected that is treated in a wastewater treatment plant (wwtp) as well as (3) the level of wastewater treatment (see Table 1). Many countries within the Danube Basin are already members of the European Union. These countries have to implement the legislation of the EU within a given time frame. With respect to municipal wastewater treatment, the Urban Waste Water Treatment Directive [91/271/EEC] has to be considered. All agglomerations above 2,000 p.e. (Population equivalent) have to be connected to sewer systems.

The wastewater entering collecting systems shall be subject to secondary treatment or an equivalent treatment before discharge. Furthermore, requirements for discharges from urban wastewater treatment plants to sensitive areas that are subject to eutrophication are stipulated. For the parameters, TN and TP effluent concentrations as well as removal rates are regulated. For one or both of these elements removal efficiency standards have to be applied depending on the local situation. The values for concentration or for the percentage of reduction shall be applied. Based on the willingness of Romania to declare the Danube catchment as a "sensitive area", it can be expected that the whole Danube catchment is going to become a "sensitive area", which is well in line with the needs for eutrophication abatement in the Western Black Sea coastal areas (Kroiss *et al.* 2006). To fully

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Table 1 | Level of treatment of wastewater from agglomerations ≥2,000 p.e. (population equivalent). Numbers indicate the percentage of the total wastewater from these agglomerations (ICPDR 2010)

		A	BG	CZ	HU	RO	SK	SI	UA
Collected in public sewerage, no treatment	%	100	85	92	100	47	73	73	100
Collected, at least primary treatment	%	100	61	90	85	32	71	62	90
Collected, secondary treatment (C-removal)	%	100	60	90	84	28	70	61	90
Collected, tertiary treatment (N and/or P removal)	%	97	2	77	50	<1	19	23	0

comply with implementation of the EU Urban Waste Water Treatment Directive (UWWTD) high efforts are required from the member states. Numerous new plants have to be erected and several existing plants have to be upgraded to meet the effluent requirements.

This paper investigates the costs of wastewater treatment within the Danube catchment for the countries A (Austria), CZ (Czech Republic), SK (Slovakia), HU (Hungary), SL (Slovenia), RO (Romania), BG (Bulgaria) and UA (Ukraine). Additionally costs for TK (Turkey) are presented. Additionally, the paper compares the total costs of wastewater management (including sewerage) with the incomes in the different countries.

APPROACH

Several studies on costs of wastewater treatment already have been established and cost functions have been derived for investment costs as well as for operation costs (Ødegaard 1995; Zessner *et al.* 1998). However, cost functions are strongly influenced by national characteristics. Therefore, a transfer to other countries has to consider these national characteristics.

The general approach was as follows: existing cost functions for capital costs as well as operation costs for Austrian wastewater treatment plants (Kroiss *et al.* 2001; Lindtner 2007) were adapted for the eight countries mentioned in the Black Sea catchment using "local" (national) data. Of main interest were differences in salaries, energy costs, material costs, disposal costs, etc. National data have been collected from different national and international statistics (e.g. EIA 2007; Eurostat 2007; Eustat 2007; ILO 2007). More details for different cost categories are given below.

The main assumption of the assessment was that the configurations and operation schemes of treatment plants in other countries fulfilling certain emission requirements (C-removal only (C-plants), C-removal with nitrification (CN-plants) C + N-removal (CND-plants), C + P-removal (CP-Plants), C + P + N-removal (CNDP-plants) are similar to those included in the studies on cost functions which were adapted. This implied e.g. that the efficiency of aeration, pumping, etc. is comparable.

The collection of non-monetary data helped to compare cost data across national borders (man-hours, energy consumption, chemicals consumption, etc.) Some costs, e.g. electricity for aeration and chemicals for phosphorus precipitation and sludge conditioning, ought to be related to the actual load of pollutants to the plant, while other operating costs are related to the physical size of the plant and the number of tanks and pieces of machinery it is composed of.

Cost functions show the effect of economy of scale. This effect is also considered in the adaptation of the cost functions.

Investment costs (annual capital costs)

Investment costs can be split up into costs of construction and into costs of the mechanical and electrical equipment. In Austria typically the construction costs amount to 60–70% of the total investment costs of the treatment plant (Kroiss *et al.* 2001). For the following calculations we used the assumption that 65% of the investment costs are due to construction costs. There is no significant dependency of the size of the treatment plants on the distribution of investment costs into costs of construction and costs of the mechanical and electrical equipment in Austria. The adaptation of investment costs to other countries faces

Table 2 | Investment costs of CN and CND plants in relation to C-plants (C-plants = 1). Additional investment costs for P-removal (CP and CNDP-plants) are considered as not relevant

	Construction costs	Electrical and mechanical installation costs
C-removal	1	1
C-removal + nitrification	1.08	1.06
C-removal + nitrification + denitrification	1.11	1.08

several obstacles, e.g. construction costs reflect personnel costs as well as prices for different materials like steel, cement, etc. Both personnel costs as well as the prices for materials can be obtained for different countries. The main problem is to divide construction costs into personnel costs and costs of materials.

Based on Flögl (1980), Nowak (1999) and Escobar (2007, personal communication) and on our own investigations, the following relations of personnel costs to material costs reflecting the Austrian situation were derived:

Assumptions for the relations of personnel costs to material costs

- construction costs: 55%: 45%
- machinery: 20%: 80%
- electrical installations: 45%: 55%

These assumptions were used to derive the investment costs in the other countries under investigation. A graphical presentation is given in the following figure, showing that out of the total investment costs in Austria about 55% are due to materials and 45% due to personnel costs (Table 2, Figure 1).

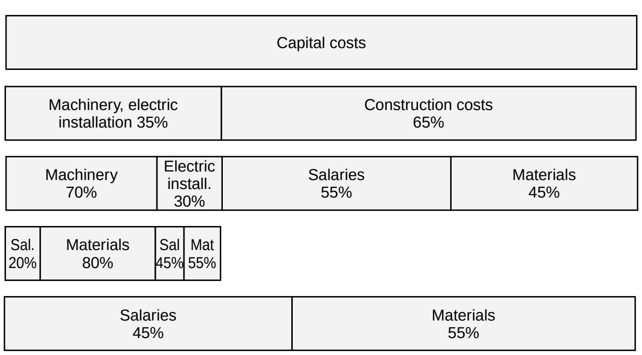

Figure 1 | Subdivision of annual capital costs used for calculations.

Based on expert judgements it was assumed that the prices for steel, concrete, and machinery are comparable to Western Europe as these goods are bought on the world market or often imported from Western Europe. Information on personnel costs will be provided below. Depending on the treatment level, investment costs of wastewater treatment differ. From literature (Flögl 1980; Nowak 1999; Kroiss *et al.* 2001) the following cost ratios of investment costs for C-, CN- and CND-plants were derived.

Finally annual capital costs (= amortisation of investments) have been calculated out of the investment costs using a real interest rate of 5% and a calculatory life time (depreciation time) of 30 years. The sum of annual capital costs and operation costs are the total annual costs used in the results section for comparison.

Operation costs

Operation costs for this study were subdivided as follows: personnel costs, energy, chemicals, sludge treatment and disposal, other costs. Assumptions and costs derived for personnel costs, energy and sludge treatment and disposal are provided in the following sections. For chemicals (precipitants and polymers) it was assumed that costs are the same as in Austria, for "other cost" a ratio of 5% of the total operation costs for plants larger 100,000 p.e. and 10% of plants smaller than 50,000 p.e. was used. Costs for maintenance are included in the other cost categories (about 5% of the total annual costs (operation costs + annual capital costs)).

Personnel costs

Information on salaries for construction workers and skilled workers was provided by (UBS 2007). The employer's contribution was obtained from the German federal statistical office (Destatis 2007). For Turkey and Ukraine no values were provided in the data base mentioned. For these two countries an internet investigation was carried out. In the current situation large differences exist in salaries. However, it has to be expected that the gap between salaries will narrow down during the next 30 years (Table 3).

Table 3 | Annual personnel costs used for cost calculations for investment costs and operation costs in €/employee year

	A	BG	CZ	HU	RO	SK	SI	TK	UA
Investment costs	32,150	4,700	11,850	7,700	4,550	7,600	12,000	6,000	2,400
Operation costs	32,150	11,600	16,900	13,800	11,458	13,750	17,000	12,500	9,850

To reflect the development of salaries the following assumptions were made:

- Investment costs: current salaries are used
- Operation costs: the difference in salaries will be 50% lower at the end of the depreciation time of the plant (30 years).

The labour productivity in the Black Sea catchment countries differs considerably. For our calculations we used the investigations on labour productivity of Eustat (2007) providing data for 2006 for A, D, CZ, HU, SK, SL, RO and BG, of OECD (2006) providing data for 2005 for TK and of ILO (2007) providing data for 2005 for UA. As the cost calculations for wastewater treatment reflect a time period of 30 years, an increase in the labour productivity has to be anticipated for the calculations of operation costs. It was assumed that in 30 years the labour productivity will be the same in all countries under investigation.

Energy consumption and energy costs

The energy consumption at treatment plants is dominated by aeration equipment ($\geq$60% in the case of anaerobic stabilisation, $\geq$70% in the case of aerobic stabilisation). Plants with additional denitrification show a lower oxygen demand as compared to plants with C-removal and nitrification as nitrate is used to reduce organic pollution. ÖWAV (2007) gives a median value for plants with and without anaerobic sludge digestion of 27 kWh/p.e. COD_{110} (25th percentile: 22 kWh/p.e. COD_{110}, 75th percentile: 29 kWh/p.e. COD_{110}). Agis (2002) shows that the consumption of mechanical and electrical energy of plants without sludge digestion is about 10% higher. Based on the oxygen demand for BOD_5-degradation, nitrification and denitrification, the removal efficiency and a share of 60% of the total energy consumption of the plant for aeration, the following factors can be derived (Table 4).

Table 5 shows a comparison of electricity costs in several countries. Compared with Austria (ca. 7.9 €/100 kWh), electricity prices were 60% lower in Ukraine and 40% lower in Bulgaria. In all other countries considered in this study the prices were almost similar to Austria (-5% up to $+20$%) (EIA 2007; Eurostat 2007; Tsarenko 2007).

Costs of sludge treatment and disposal

The costs of sludge treatment and disposal depend on the amount of sludge produced and the disposal method. The amount of sludge produced depends on the treatment steps of the plants: CN- and CND-plants produce (slightly) less sludge than plants with C-removal only. P-removal increases the amount of sludge and therefore increases the costs of sludge management (dewatering, chemicals, disposal, etc.). Increasing P-loads to be removed (e.g. due to the consumption of P-based detergents) increase the amount of sludge produced. A replacement of P-based detergents, e.g. by Zeolites, also increases the amount of sludge produced. The daily specific sludge production varies between 40 and 60 g dm/p.e.d (14–25 kg dm/p.e. year) (upper limit for plants with P-removal). In plants with aerobic sludge stabilisation the amounts of sludge are slightly higher than in plants with anaerobic stabilisation.

For the sludge production in treatment plants without P-removal an amount of 40 g dm/p.e. d (14.6 kg dm/p.e. y) was assumed. The production of sludge at CP-plants is about 25% higher than at plants with C-removal only (if no P-based laundry detergents are used). The removal of 1 kg P produces additional dry matter of 9.7 kg dm using Fe salts and 7.5 kg dm using Al salts ($\beta = 1.8$). Depending on the type of the dewatering device the costs in Austria vary from

Table 4 | Energy consumption of CN and CND plants in relation to C-plants (C-plants = 1)

	Energy costs
C-removal	1
C-removal + nitrification	1.3
C-removal + nitrification + denitrification	1.2

Table 5 | Costs of electricity in €/100 kWh excluding VAT (stand 1.1.2007), price for industrial consumers, type Ie (2,000 MWh a) (Eurostat 2007)

Country	**AT**	**BE**	**BG**	**CY**	**CZ**	**DE**	**DK**	**EE**	**EL**	**ES**	**EU-27**	**FI**	**FR**	**HR**	**HU**	**IE**
Price/100 kWh	*7.86*	8.80	*4.65*	10.48	*7.83*	*9.46*	6.38	5.34	6.98	8.10	8.22	5.42	5.41	*5.97*	*8.12*	11.25
Country	**IT**	**LT**	**LU**	**LV**	**MT**	**NL**	**NO**	**PL**	**PT**	**RO**	**SE**	**SI**	**SK**	**UK**	**TK***	**UA†**
Price/100 kWh	10.27	4.43	9.63	5.48	8.97	9.2	7.24	5.41	8.6	*8.42*	7.07	*7.5*	*9.23*	9.5	*9.4*	*3*

*EIA (2007).
†Tsarenko (2007).

91 (belt-type filter) to 121 €/t dm (centrifuge) (Kroiss *et al.* 2001). Compared to Austria, sludge dewatering in the other countries under investigation is between 10% and 20% cheaper if costs for energy, personnel costs and costs for steel concrete and machinery are considered as discussed before (Table 6).

The data base on sludge management in many of the Black Sea countries is very weak and does not allow detailed analysis. Data on sludge disposal routes are often contradictory. Data on costs show very broad ranges – from almost zero € per ton of sludge to costs higher than in Austria. Agreement exists only on the fact that incineration of sludge is of minor importance in Eastern Europe (partly sludge is incinerated in cement kilns). In addition the disposal in landfills and in drying platforms (located at the treatment site) seem to be important disposal routes.

In the long run it has to be assumed that, at least in the EU member states, the disposal of sewage sludge in landfills will be prohibited and incineration will become a more relevant disposal route. For our calculations we assumed (time period: next 30 years) the following disposal routes: 30% landfill, 30% incineration, 20% agriculture and 20% composting in all countries except Austria. For Austria current disposal routes and costs are used. For the costs a similar approach as for the wastewater treatment plants was used: Austria was chosen as the base and country specific costs were derived in accordance with the shares of material costs and personnel costs (Table 7).

RESULTS

Investment costs in Austria for a CNDP plant with 100,000 p.e. are about 250 €/p.e. design. Compared to Austria, the investment costs for CNDP plants in the other countries considered are 15% (CZ) up to 30% (UA) lower. Investment costs have been converted to annual capital costs (amortisation of investments). These annual capital costs amount to 13 (A), 11 (CZ) and 9.5 (UA) €/p.e. y (5% real interest rate, 30 years depreciation). Investment costs of plants without denitrification are ~2% lower, plants with C-removal ~9% lower.

For CNDP-plants in Austria operations costs are about 11 €/p.e. y in larger plants (above 100,000 p.e.) and about 16 €/p.e. y in smaller plants (10,000–50,000 p.e.). In the other countries operation costs are 18% up to 30% lower. This is valid for all plants considered. The major cost category of operation costs in Austria is "personnel" (40% in small plants, 30% in large plants). In the other countries investigated, personnel costs amount to 31% (SK) to 48% (UA) in small plants and 23% (SK) to 40% (UA) in large

Table 6 | Costs for sludge dewatering

€/t dry matter	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
Chemicals	35	35	35	35	35	35	35	35	35
Personnel	43	34	31	24	32	25	28	33	40
External services	12	10	9	7	9	7	8	9	11
Electricity costs	12	7	12	13	13	15	12	15	5
Sum	102	86	87	79	89	82	83	92	91

Table 7 | Sludge disposal costs in € per ton dry matter

Sludge disposal costs €/t dry matter	A	BG	CZ	HU	RO	SK	SI	TK	UA
	142	76	83	76	74	76	82	77	71

plants. In all countries in small plants the main cost category is "personnel". However, in large plants in HU and SK energy costs represent the highest shares. Operation costs of plants with nitrification but without denitrification are for small plants 8% (A) to 10% (UA) lower, for large plants 10–12% lower compared to CNDP plants. Operation costs of plants with C-removal only are about 20% lower as compared to CNDP plants.

For the calculation of the total annual costs the investment costs (annual capital costs) had to be transferred as they are given for the design capacity. We assumed a mean pollution load of the plant of 70% of the design load (which corresponds to ~90% degree of utilization, as design is based on peak loads (low temperatures)). Compared to Austria the annual costs for CNDP plants in the other countries are 18% (CZ) up to 27% (UA) lower (Figure 2).

Annual costs of plants with nitrification are 4–5% lower compared to CNDP plants. There is no significant difference in the annual costs of CN-plants and CND-plants. Annual costs of plants with C-removal only are ~12% lower compared to CNDP plants. For all plants in all countries operation costs amount to 30–38% of the total annual costs. The larger the plants, the higher the contribution of operation costs.

DISCUSSION

Total annual costs (including operation costs and amortisation of investments) for wastewater treatment vary in the range of 17 to 30 €/p.e. y for large plants (>100,000 p.e.) and 30 to 40 €/p.e. for smaller plants (10,000–50,000 p.e.). The treatment level achieved (carbon removal, nitrification/denitrification, phosphorus removal) has only a small influence on these costs.

Looking at the results of different countries it is obvious that differences of comparable treatment plants are not specifically high (not more than 10 €/p.e. y). The reason for this is that of the important cost factors (i) costs for materials are not different in different countries, (ii) energy costs are almost equal in most of the countries as well and (iii) in respect of personnel cost significantly lower salaries are to a certain extent counterbalanced by lower labour productivities.

However, the incomes in countries like Bulgaria, Romania or Ukraine are 85 to 90% lower than in Austria while waste treatment costs are almost the same. This makes it apparent that financing of wastewater treatment will be a much higher challenge in low income countries. Furthermore, it has to be considered that wastewater treatment plants are only one part of the needed water infrastructure. Water supply and sewerage have to be considered as well. For wastewater management (sewerage and wastewater treatment) about 70% of the total annual costs are required for construction and operation of sewer systems alone (Kroiss *et al.* 2001). Only about 30% are required for wastewater treatment. Thus, total annual costs for wastewater management (sewerage and treatment) of at least 90€/p.e. y can be estimated even for low income countries (assuming a wastewater production of 1 p.e. per inhabitant).

The average specific income in the Ukraine is less than 2,400 € per inhabitant and year, in Romania and Bulgaria slightly higher. Figure 3 shows the relation of total costs for wastewater management per population equivalent and year to the average yearly income in the different countries. Wastewater charges of 90 €/y per inhabitant in Ukraine would mean expenditures of 3.7% of the income for a one person household with average income, with additional need for charges for water supply. Assuming a four person

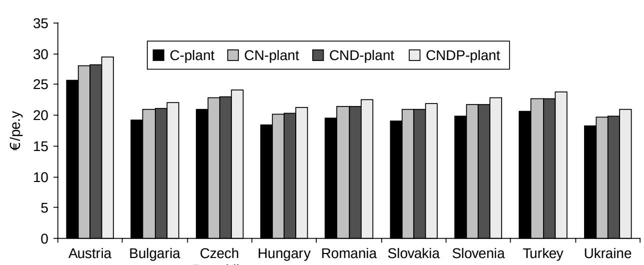

Figure 2 | Annual costs (capital costs plus operation costs) of wwtps >100,000 p.e. design.

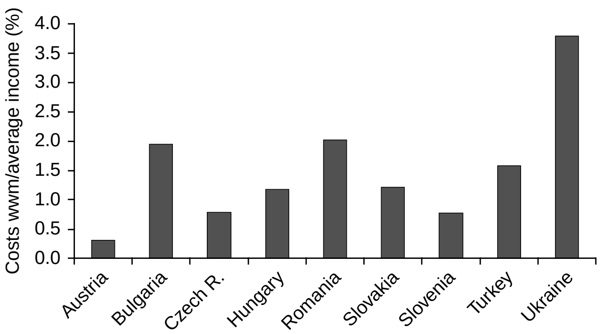

Figure 3 | Costs for wastewater management per p.e. and year in relation to an average income per inhabitant and year.

household with only one income of 2/3 of the average, expenditures for wastewater disposal would increase to more than 20% of the household income in Ukraine and still more than 7% in Hungary, while in Austria these costs are still less than 2% in such a case.

It is highly unlikely that the incomes in the low income countries (even though several of the countries have joined the European Union) will increase so fast that financing wastewater management completely by charges from the population equivalents connected is feasible. Therefore the implementation of the Urban Waste Water Directive requires other approaches for financing wastewater treatment at least for the next decades.

CONCLUSIONS

The investigations presented show a comparison of costs for different treatment levels in different countries of the Danube River Basin and Turkey. Results indicated that:

- the costs for energy are similar in most of the countries except Bulgaria and Ukraine with significantly lower costs,
- in respect to personnel costs lower salaries in low income countries are to a certain degree counterbalanced by lower labour productivities; nevertheless, differences in costs for wastewater treatment in different countries are mainly because of differences in personnel costs,
- there are no significant differences in costs for chemicals and materials in the countries investigated,
- wastewater treatment including nitrogen and phosphorus removal in plants with more than 100,000 p.e. in Austria costs about 30 €/p.e. y (annual capital costs and costs for operation and maintenance),
- costs for wastewater treatment in low income countries are only less than 30% lower than in a high income country such as Austria while average incomes are up to 90% lower,
- annual capital costs (amortisation of investments) account for 60 to 70% of the total annual costs,
- about 45% of the capital costs are due to salaries and about 55% to construction materials, installations, machinery,
- operation costs are highly influenced by personnel and energy costs; nevertheless, sludge disposal is another important cost factor, which may account for up to 40% of the operation costs,
- the treatment level (carbon removal, nitrification/denitrification, phosphorus removal) has only a minor impact on costs of treatment,
- sewer construction and operation is the main cost factor of wastewater management,
- in low income countries such as Ukraine the costs for wastewater management (sewerage and treatment) may account for 20% and more of a household income, while it is usually far below 2% in Austria,
- therefore, regardless of the required level of treatment, financing wastewater management completely by charges of the population equivalents connected is not feasible in several countries investigated.

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