Affordability of waste water treatment in Danubian countries

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Abstract: This paper investigates the costs of waste water treatment within the Black Sea catchment countries A, CZ, SK, HU, SL, RO, BG, UA and TK and discusses the affordability of the related costs. The annual costs of waste water treatment in Black Sea catchment areas are in the 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 waste water management (sewer development plus treatment) amount at least to 90€/pe.y for large CNDP-plants. Waste water charges of 90€/y (CNDP) per inhabitant or more are not affordable for many households. Financing waste water management completely by charges of the population equivalents connected is not feasible in several countries investigated. Therefore other approaches for financing waste water treatment are required.

Key words: waste water treatment costs, Black Sea catchment, affordability

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 waste water management and best agricultural practice.

Within the Danube countries the status of waste water management differs considerably. Differences exist in (1) the degree of the population connected to sewer systems, (2) the part of waste water collected that is treated in a waste water treatment plant (wwtp) as well as (3) the level of waste water treatment. Many countries within the Danube Basin are already members of the European Union. These countries have to implement the legislation of the EU within fixed deadlines. With respect to municipal waste water treatment, the Urban Waste Water Treatment Directive [91/271/EEC] has to be considered. All agglomerations above 2000 pe (Population equivalent) have to be connected to sewer systems. The waste water entering collecting systems shall be subject to secondary treatment or an equivalent treatment before discharge. Furthermore, requirements for discharges from urban waste water treatment plants to sensitive areas that are subject to eutrophication are stipulated. For the parameters, TN and TP concentrations as well as a percentage of reduction are fixed. 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 apply. Based on the willingness of Romania to declare the Danube catchment as "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 comply with the full implementation of the EU Urban Waste Water Treatment Directive (UWWTD) requires high efforts from the member states. Numerous new plants have to be erected and several existing plants have to be upgraded to meet the effluent requirements.

In some Black Sea countries (e.g. the Russian Federation), discharge standards are not based on concentrations, but on loads. These load limits depend on the level of dilution offered by the receiving waterbody, since the aim is to achieve compliance with environmental quality standards. As the level of rainfall/dilution varies from year-to-year, the discharge standards have to be adapted.

This paper investigates the costs of waste water treatment within the Black Sea catchment countries A (Austria), CZ (Czech Republic), SK (Slovakia), HU (Hungary), SL (Slovenia), RO (Romania), BG (Bulgaria), UA (Ukraine) and TK (Turkey) and discusses the affordability of the related costs. Investigations were carried out in the end of 2006 until the middle of 2007.

APPROACH

Several studies on costs of waste water 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 the national characteristics.

The general approach was as follows: Existing cost functions for capital costs as well as operation costs for Austrian waste water 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/wages, energy costs, material costs, disposal costs, etc.

The main assumptions 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 over national borders (manhours, 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 annual capital costs are due to construction costs. There is no significant dependency of the size of the treatment plants on the distribution of annual capital costs into costs of construction and costs of the mechanical and electrical equipment in Austria.

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

Based on (Flögl, 1980, Nowak, 1999, Escobar, 2007 personal communication) and on own investigations based on (Statistisches Bundesamt 2007), 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

- Ø *construction costs:* *55% : 45%*
- Ø *machinery:* *20% : 80%*
- Ø *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.

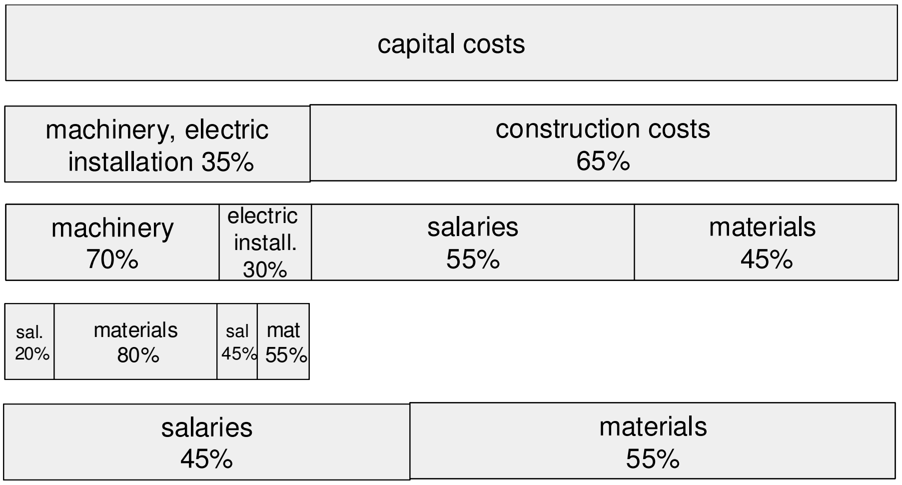

Figure 1. subdivision of annual capital costs used for calculations

Based on expert judgements it was assumed that the prices for steel, concrete, 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 waste water 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.

Table 1. investment costs of CN and CND plants in relation to C-plants (C-plants = 1)

	construction costs	Electr. and mechanic. installation costs
C-removal	1	1
C-removal + nitrification	1,08	1,06
C-removal + nitrification + denitrification	1,11	1,08

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 pe and 10% of plants smaller than 50.000 pe was used.
Costs for maintainance are included in the other cost categories (about 5% of the total annual costs (operation costs + annual capital costs)).

Personnel costs
Information on wages/salaries in 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 wages/salaries. However it has to be expected that the gap between salaries will narrow down during the next 30 years.
To reflect the development of wages/salaries the following assumption were made:

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

Table 2. Annual labour 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	32150	4700	11850	7700	4550	7600	12000	6000	2400
operation costs	32150	11600	16900	13800	11458	13750	17000	12500	9850

The labour productivity in the Black Sea catchment country differs considerably. For our calculations we used investigations on the 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 waste water 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 (≥ 60% in the case of anaerobic stabilisation, ≥ 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/pe COD_{110} (25 % percentile: 22 kWh/pe COD_{110}, 75 percentile: 29 kWh/pe 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 3. 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

Compared to Austria (ca. 7.9 €/100 kWh) the electricity prices were 60% lower in Ukraine and 40% lower in Bulgaria. In all other Danubian countries the prices were almost similar to Austria (- 5% up to + 20%) (Eurostat 2007a, EIA, 2007, Tsarenko, 2007).

Costs for 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 of the treatment steps of the plants: CN- and CND-plants produce (slightly) less sludge as 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 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 to 60 g dm/pe.d (14 – 25 kg dm/pe.year) (upper limit for plants with P-removal). In plants with aerobic sludge stabilisation the amounts of sludge are slightly higher with anaerobic stabilisation.

For the sludge production in treatment plants without P-removal an amount of 40g dm/pe.d (14.6 kg dm/pe.y) was assumed.

The production of sludge of CP-plants is about 1/4 higher as 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 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, personal costs and costs for steel concrete and machinery are considered as discussed before.

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.

On 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 waste water treatment plants was used: Austria was chosen as the base and "national" costs were derived according material costs and personnel costs.

RESULTS

Investment costs in Austria for a CNDP plant with 100.000 pe are about 250€/pe design.

Compared to Austria the investment costs for CNDP plants in the other countries considered are 15% (CZ) up to 30% (UA) lower. The respective annual costs amount to 13 (A), 11 (CZ) and 9.5 (UA) €/pe.y (5% real interest rate, 30 years depreciation).

Investment costs of plants without denitrification are ~ 2% lower, plants with C-removal ~ 9% lower.

Compared to Austria (about 11 €/pe.y in larger plants (above 100.000 pe), 16€/pe.y in small plants (below 50.000 pe)) the *operation costs* for CNDP-plants in the other countries are 18% up to 30% lower. This is valid for small as well as for large plants. 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 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 only 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 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.

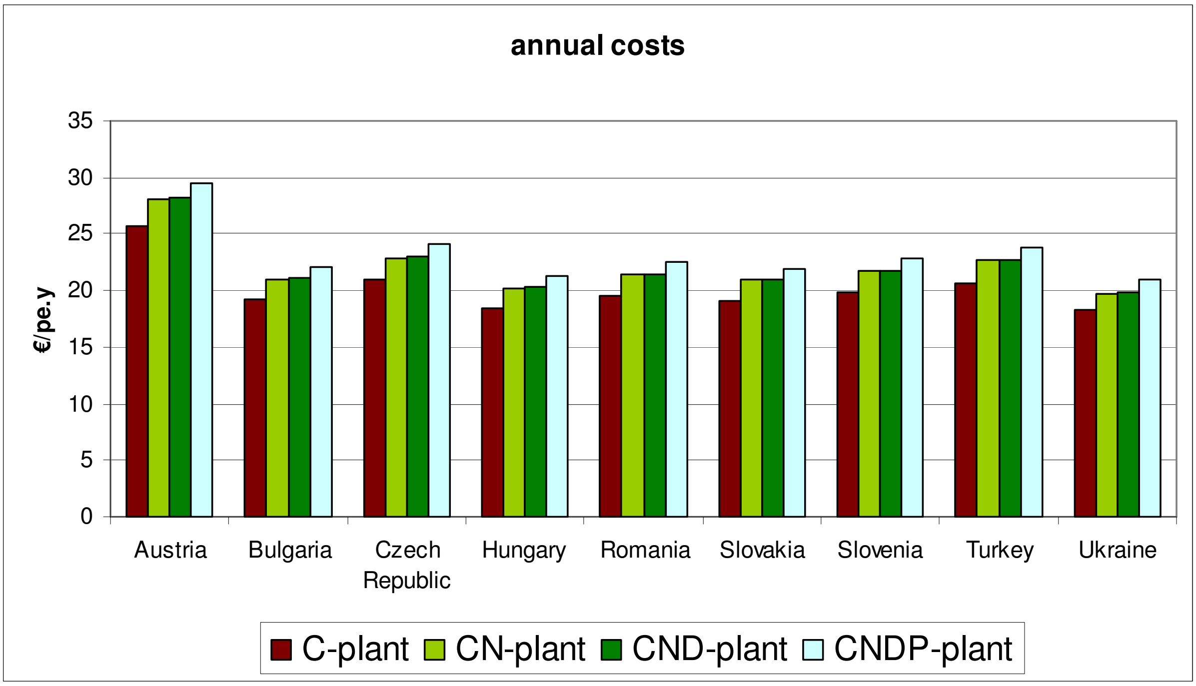

Figure 1. annual costs (capital costs plus operation costs) of wwtps > 100000 pe design

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.

Costs for the sewer system

Waste water management includes in addition to the treatment of waste water in treatment plants the related sewer systems.
Using a comparable approach as for the costs of waste water treament the total annual cost for sewer systems compared to Austria are 17% (CZ) to 28% cheaper (SK). For the assumption that

waste water treatment costs amount to 30% total costs, total costs (waste water treatment plus sewer development) of 92 (UA) to 104 (CZ) €/pe.y were obtained (Austria (127 €/pe.y).
The total costs of waste water management in the countries under investigations are 18% (CZ) to 27% (SK) lower as in Austria.

DISCUSSION

As shown above, the annual costs of waste water treatment in Black Sea catchment areas are less than 30% lower than in Austria. However the incomes in countries like Bulgaria, Romania or Ukraine are 85 to 90% lower.
In respect to costs of waste water management sewer development is the more costly part. Roughly 70% of the costs can be related to sewer development.
As depicted above in the minimum the annual costs for large CNDP-plants amount to almost 20€/pe.y (in smaller plants even more). This leads to total annual costs for waste water management of at least 90€/pe.y for large CNDP-plants.
The average income in the Ukraine is less than 2400 €/year, in Romania and Bulgaria slightly higher. Figure 2 shows the relation of total costs for waste water management per population equivalent and year to the average yearly income in the different countries. According the affordability index cited in the literature, which denotes the ratio of the total annual costs and the total net household expenditures, tolerable values for environmental protection are about 1- 3% of the expenditures. In the case that waste water management would be the only expenditure for environmental protection waste water charges of 90€/y (CNDP) per inhabitant or more are not affordable according the index even for one-person-households with full income. However the applicability of this index is questionable for persons/countries with very low incomes. For these persons/countries the major part of the income is required to cover the basic needs (food, dwelling, clothing, etc.) and less money will be available for additional expenditures. The affordability index would be more useful be related to the expenditures done in addition to the basic needs.

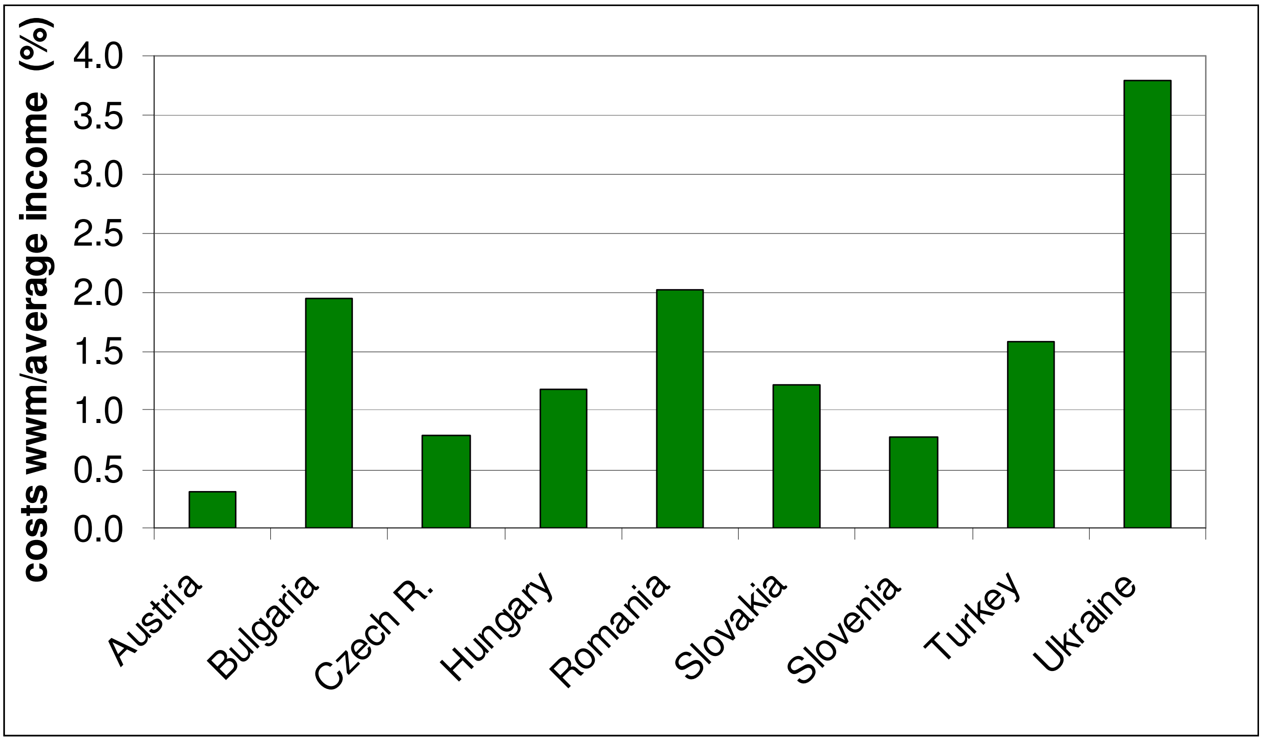

Figure 2. costs for waste water management (per pe and year) in relation to an average income

It is highly unlike that the incomes in the less developed countries (even several of the countries joined the European Union) will increase that fast that financing waste water management completely by charges of the population equivalents connected is feasible. Therefore the implementation of the Urban Waste Water Directive requires other approaches for financing waste water treatment.

SUMMARY

The largest differences for costs were found for the personnel costs. Compared to Austria (ca. 32,000 €/y total costs including employers contribution) the wages /salaries in Ukraine are more than 90%, in Bulgaria and Romania about 85% lower. However differences in labour productivity are counteracting to some extend the height of the salaries. The range of costs for electricity is narrower: Compared to Austria (ca. 7.9 €/100 kWh) the electricity prices are 60% lower in Ukraine and 40% lower in Bulgaria. In all other Black Sea countries considered the prices are almost similar to Austria (- 5% up to + 20%). The costs for construction materials, machinery and chemicals like precipitants are in all countries similar to those in Austria.

In Austria investment costs for plants with Carbon, Nitrogen and Phosphate-removal (CNDP-plants) > 100,000 pe are about 250 €/pe (45% salaries/wages, 55% construction materials, installations, machinery). In the Black Sea countries the calculated investment costs are in the maximum 30% lower than in Austria.

Sludge management strongly influences operation costs. For example in Austria these costs amount to almost 25% of the operation costs of about 11 €/pe (plants > 100,000 pe). Unfortunately no reliable data base on costs of sludge disposal in Eastern Europe is available. Assuming similar costs for sludge disposal in the other countries as in Austria the share of these costs rises up to 45% in the Ukraine. The total operation costs in the considered Black Sea countries are 18 to 30% lower compared to Austria.

The total annual costs (capital costs + operation costs) for large CNDP-plants (> 100.000 pe) in Austria are about 27 € / pe. Calculations show in the maximum 27% lower annual costs in the countries considered.

The impact of the level of treatment influences the costs only slightly: 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 (including nitrification) and CND-plants (including nitrification and denitrification). Annual costs of plants with carbon (C) -removal only are ~ 12% lower compared to CNDP plants (3 – 4€/pe.y less) (including nitrification, denitrification and phosphorus removal).

The removal of 1 kg P by precipitation causes costs independently from the countries of about 4€, mainly due to the costs for precipitants and the sludge disposal. An upgrade of plants with C-removal and Nitrification with a Denitrification step to increase N-removal from 40 to 75% results in additional costs of only 0.4 €/kg N removed as the increasing investment costs are counteracted by decreasing electricity costs for aeration.

The costs to apply to an emission standard of 1 mgP/l instead of 2 mg P/l amounts to additional costs for precipitants and dewatering of about 0.4€/pe.y.

The costs derived for waste water treatment and sewer development using "national" costs show annual costs of at least 90€/pe.y for CNDP-plants. Compared to the incomes in the countries investigated these costs are beyond the "affordability" of the majority of the considered countries. Thus, financing waste water management completely by charges of the population equivalents connected is not feasible in several countries investigated. Therefore other approaches for financing waste water treatment are required.

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