UNDP-GEF Black Sea Ecosystem Recovery Project (PIMS 3065)

Cost Effective Measures to Minimise Nutrient Pollution

(Project output 3.1)

Final Report on Tasks 1b/2b/3b

Case study on calculating cost-effective measures to tackle nutrient pollution from the agricultural, municipal and industrial sectors in the Black Sea

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January 2008

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1 Introduction

In order to address nutrient pollution in the Black Sea region measures in the agricultural, industrial and urban sector have to be taken. In order to use the limited financial resources most efficient, measures to tackle the pollution should be selected against the cost effectiveness criteria.

This report is based on the methodology developed under Task 1a/2a/3a and analyses of previous work carried out mainly in the EU Member States and addresses:

- Based on previous work in EU Member states (development of programs of measures for the Nitrate Directive and the WFD), an indicative list of measures for reducing nutrient emissions from **agriculture** has been developed.

- Cost effectiveness in **waste water treatment** including estimations of emissions reduced and costs of different upgrading options in municipal sewage treatment works; the costs will consider effects of the “economy of scale” (dependency of costs on the design capacity of the plant). The assessment compares the situation in Austria with Bulgaria, Czech Republic, Hungary, Romania, Slovakia, Slovenia and Turkey.

- Nutrient emissions from **industrial** sources in selected Danube countries (Austria, Hungary, Romania and Bulgaria) have been evaluated based on information from the ICPDR emission inventory 2002 (http://danubis.icpdr.org), which compiles emissions from major industrial facilities on the national level. Due to the limited resources in this project, one industrial sector was selected to evaluate potential measures to reduce nutrient emissions to surface waters - the fertiliser manufacturing industry. Depending on different types of fertiliser products (N-, P-, NP- or NPK-fertiliser) different production lines have been investigated in terms of liquid process waste waters containing nitrogen and/or phosphorus, which are discharged to surface waters after an adequate treatment. Emission levels have been defined which can be associated with the application of best available techniques for production and emission abatement to water and to air in accordance with EU IPPC directive 96/61/EC.

The comparison of the results of all case studies is discussed in a further report called ”Comparison of results- guidelines on how to select the most cost effective measures”.

2 Case study on nutrient reduction in agriculture

Agriculture is a major land user in the Black Sea Region contributing importantly to eutrophication in the Black Sea region. For example, one-third of Turkey's and Georgia's agriculture lands are in the Black Sea basin. UNDP (2007). As a consequence, agriculture has an important responsibility for maintaining or improving the quality and quantity of water resources to reach the environmental targets set for the Black Sea region.

Although agriculture has played a significant role in nutrient leaching in the past, economic recession in the former communist countries in the 1990's has resulted in:

- dramatic reductions in the application of mineral fertilizers
- closures of large livestock farms (significant point sources of agricultural pollution)

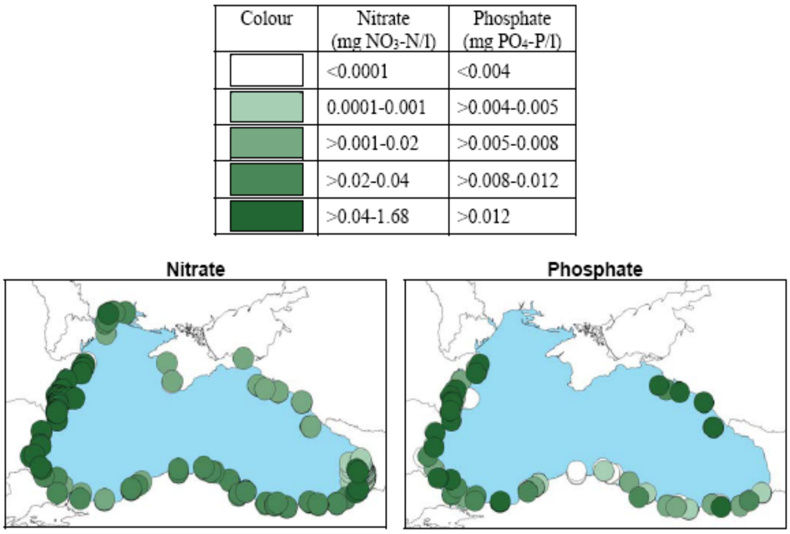
Table 1: highlights the significant decrease in livestock numbers in the region. Current livestock numbers (2004) are only 1/3 of the total livestock in 1998 UNDP (2007).

Table 1: Dynamics of livestock numbers in the six Black Sea coastal country sub-basins (in millions) UNDP (2007).

	1960	**1970**	**1988**	**1997**	**2003**
Cattle	47.8	56.2	65.6	35.3	23.4
Pigs	27.0	31.4	40.3	20.6	15.2
Sheep & goats	46.7	46.2	47.1	22.3	15.4
Poultry	207.7	262.0	452.4	290.6	356.5

Although fertilizer application decreased significantly after the economic crisis (e.g. in Romania application levels fell below 1970 rates), recent, desirable economic development in these countries are likely to increase nutrient application and emissions in the future.

As indicated in the Black Sea Transboundary Diagnostic Analysis (UNDP (2007), data from the 2005 World Bank World Development Indicators database revealed that the Black Sea country with the highest rate of fertilizer application rates is Turkey. On the other hand, Russia and Ukraine have the lowest application rates, with application rates in Bulgaria, Georgia and Romania in the middle. However, a rough assessment of data from Georgia, Russia and Romania does indicate that between 1997 and 2004, inorganic fertiliser application rates have increased for cereal, oilseed and leguminous (bean and pea) crop production UNDP (2007). As shown in Figure 1, fertilizer application rates can be directly linked to the mean concentration of N and P in surface waters.



Colour	Nitrate (mg NO_3-N/l)	Phosphate (mg PO_4-P/l)
⬜	<0.0001	<0.004
🟩	0.0001-0.001	>0.004-0.005
🟩	>0.001-0.02	>0.005-0.008
🟩	>0.02-0.04	>0.008-0.012
🟩	>0.04-1.68	>0.012

Figure 1: Mean concentrations of nitrate and phosphate in surface waters of the Black Sea, 2000-2005 UNDP (2007)

Since the role of agriculture has been minor in the 1990's, agriculture in the Black Sea Region now has a vast potential, especially to apply best farming practices. If mobilized, the region can turn self-sufficient in food which will act as a strong stimulant in intra and inter-regional trade. Privatization and application of advanced agricultural extension services and other techniques including introduction of modern animal husbandry, poultry, and dairy industry supported with adequate capital inputs are considered as the key elements to agricultural development. Its growth will lay the ground for agro-industry, help self-sufficiency in the supply of food-stuffs and save precious hard currency which can be diverted to more productive sectors of the economy.

The challenge will be, therefore, to cancel out these possible increases by actively reducing emission levels from agricultural sources, in order to keep nutrient inputs at their current low levels while also allowing for the effects of economic development in countries in the middle and lower regions of the Danube Basin.

This reports aims to support this target by proposing a list of potential measures that reduce environmental pressures from agriculture without limiting the economic growth in general.

2.1 Introductory remark

As usually defined, the aim of cost-effectiveness analysis (CEA) is to develop a ratio that indicates the costs of achieving a per unit change in a specified physical outcome1, with an alternative being to determine the minimum cost of meeting a specified physical outcome. The numerator or 'cost' element represents the estimated financial or economic costs of meeting the specified target of adopting a particular option, while the denominator reflects the relevant physical outcome.

Within CEA, costs are typically defined in terms of the direct financial or economic costs of implementing a proposed measure, with effectiveness measured in terms of some physical measure of environmental outcome. When comparing different European approaches[1] it comes obvious that the calculations of cost effectiveness for agricultural measures can suffer from a number of problems, such as:

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[1] United Kingdom, Austria, Helsinki Commission for the Baltic Sea, Sweden, Netherlands, France

- Lack of a common framework for the calculation of agricultural measures. While in the UWWTP and for industry such a framework exists for at least 30 years no such framework was developed for agricultural measures.
- when the proposed measure has more than one benefit (e.g. improvements in morphology, nutrients and chemical quality), it might be difficult to allocate the share of costs to each benefit.
- Missing cost data. While data on costs has been systematically been collected for measures tackling point sources
- Effectiveness of measures is often difficult to judge as it might depend on the local conditions under it is applied (e.g. soil conditions)

However there are also some similarities between the different European approaches, from which BS countries can learn:

- The list of measures to tackle diffuse pollution from agriculture contain similar sets of measures
- Qualitative descriptions are mostly used to describe cost and effects.
- In order to better understand the effectiveness of measures it is described by several attributes. The attributes vary in detail, but contain mostly effect, time frame, geographical scale
- Cost calculations vary widely and do not necessary cover all direct or indirect cost categories. Cost calculations are often based on local case studies or modelling.

Due to this data gaps, inconsistencies, different approaches, the lack of modelling capacity and the limited resources it is impossible to generate the same clear picture as for the urban waste water and industry sector with respect to cost effectiveness. Nevertheless the information presented in the following section allows making judgments on the cost efficiency of measures taken to tackle agricultural diffuse pollution

2.2 Measures to reduce agricultural pressures

This aims at identifying the cost effectiveness of measures taken in agriculture to reduce nutrient leaching into groundwater and/or surface waters. Based on previous work in EU Member States (development of programs of measures for the Nitrate Directive and the WFD), an indicative list of measures for reducing nutrient emissions into groundwater and surface waters has be developed based on former UNDP/GEF projects[2] in the Black Sea and Danube Basin. However this list of potential measures is not closed / exhaustive and other measures may also be considered. The measures are grouped into the following categories:

- Land use
- Soil management
- Fertilizer and manure management
- Animal feeding
- Farm infrastructure
- Education and Training

Each category contains one or more sub-measures. The list of these sub-measures is not exclusive and several more measures exist. The focus in the selection was on measures that could easily be established under the codes of “good agricultural practice”

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[2] For example: Development of Black Sea Strategic Action Plan (adopted by the six boarding countries in 1996); Introducing Integrated Coastal Zones Management practices to Black Sea coastal zones as endorsed by the Odessa Declaration of 1993; Marine Environmental Assessment of the Black Sea. For a more comprehensive list of past UNDP/GEF projects related to Black Sea management, please visit: http://www.undp.org/gef/05/portfolio/writeups/iw/blacksea_envmanagement.html

The assessed measures are not presented in any order of cost effectiveness as detailed calculations where not possible for three main reasons i) lack of a consistent methodological framework for calculating costs, ii) lack of detailed cost data, iii) lack of detailed models to estimate effectiveness for the Black Sea region, and i) finally the limited resources given in this project. However based on previous work carried out by Austria, UK, Germany and Denmark and the Helsinki Commission as wall as additional scientific research the following information has been compiled, allowing first indications on cost effectiveness.

Each measure is presented by nine attributes, which are (for details see methodology part[3]):

I. **Primary Effect:** Mainly the way or the extent to which this measure could contribute to the achievement of the set environmental objective
II. **Water-related side effects**: additional water-related effects beside the primary effects.
III. **Non-water-related side effects:** all other effects which are not directly related to water such as social effects, effects on other environmental aspects or income.
IV. **Geographical scale of the effect:** local, regional, basin wide scale of the effect
V. **Time scale:** required for measures to become effective (short term refers to three years, medium to five and long term moiré than five years)
VI. **Durability of an effect:** Time the effects holds on
VII. **Adaptability:** Provides information on how a measure can be improved or adapted to circumstances
VIII. **Certainty of the effect:** How certain a effect will take place
IX. **Costs:** Costs refer to direct costs and if available to indirect wider economic costs.

2.2.1 Land Use

2.2.1.1 Converting Arable Land to Extensive Grassland

Replacing intensive agriculture with permanent grassland reduces nitrogen and phosphorus losses, which is of particular importance for drinking water protection areas.

Effect analysis

Primary Effect

The conversion of arable land to extensive grassland effectively reduces the nitrogen content in soils, since applying additional nutrient inputs, which is a common agriculture practice, is avoided. This measure has the potential to reduce nitrate losses by 95%. With respect to phosphorus, significant reductions in P leaching takes time in areas with initial high P levels; however, P losses due to surface run-off are immediately reduced. It is estimated that conversion to un-utilised grassland can reduce phosphorus by 50% Helsinki Commission (2007). Additionally, permanent plant cover reduces the potential for soil erosion.

Water-related side effects

An increase in the biodiversity on extensively managed grassland is possible.

Non-water-related side effects

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[3] See also Report on Tasks 1a/2a/3a - Methodology for selecting cost-effective measures to tackle nutrient pollution from the agricultural, municipal and industrial sectors in the Black Sea

The conversion of arable land is likely to significantly affect the market balance, since it means that land is taken out of production (and replaced by extensively used grassland).

Geographical scale of the effect

☑ local ☑ regional ☑ Basin- wide

Time scale

Until implementation:	medium-term
Until effectiveness:	Measures may become effective in the short-term, as well as in the medium- or long-term, depending on regional peculiarities.

Durability of an effect:

The durability depends on the time the land is used as grassland. When arable fields are permanently set aside then over time the danger of leaching compared to rotational fallows reduces and is relatively low.

Adaptability

High

Certainty of the effect

High

Costs

For the conversion of arable land into extensively used arable land or grassland, farmers may apply for compensation for the reduction in market revenue.

2.2.2 Soil Management

2.2.2.1 Plant Cover in Winter

A winter cover crop is planted in late summer or fall to provide soil cover during the winter. A cover crop will take up residual nitrate and other nutrients from the soil after the main crop has been harvested in the summer or early autumn, leaving less nitrate available for leaching over winter. Ensuring that the land is not left exposed helps reduce soil erosion and the mobilisation of associated pollutants.

Effect analysis

Primary Effect

Plant cover in winter can reduce nitrate leaching resulting from excess winter rainfall, as well as phosphorus leaching, which occurs through sediment transport in surface run-off. According to a Finnish study plant cover in winter can reduce erosion 10-40 % and nitrate leaching 10-70 %. (Helsinki Commission, 2007)
According to Cuttle, et al, (2007), cover crops in the UK have shown to reduce nitrate leaching by up to 50% compared with soils that were left bare over the winter. For

effectiveness against N leaching, the crop needs to take up N before the onset of winter drainage but thereafter the date of destruction is less critical. For effectiveness against P transfer, the crop does not have to be alive (i.e. straw or even a rough seedbed are equally effective) but the soil must be protected throughout the period when runoff would occur.

Water-related side effects

Plant cover in winter protects the topsoil of the fields against the erosive forces of rain, melt and runoff waters during winters. This also reduces soil erosion into waters.

Non-water-related side effects

This measure can improve soil structure by increasing the amount of organic matter in the topsoil of the fields, which decreases the topsoil's susceptibility to silting.
Further, cover crops can improve soil fertility. Legumes can add substantial amounts of available nitrogen to the soil. Non-legumes can be used to take up excess nitrogen from previous crops and recycle the nitrogen as well as available phosphorus and potassium to the following crop.

Geographical scale of the effect

☑ local ☑ regional ☑ Basin- wide

Time scale

Until implementation: Short-term

Until effectiveness: Short term

Durability of an effect:

As long as applied.

Adaptability

High, as the selection of crops can be based to local conditions

Certainty of the effect

High

Costs

Implementation is rather easy. Costs depend on the plant in question, area and whether the farm has its own machinery or contractor. Cost savings can occur due to savings of purchased nutrients.

Example from the UK:

The root balls of the harvested crop plants will hold the soil together well. In these cases, a light spring tine harrowing may be all that is necessary to assist re-growth and ground cover at a cost of £10/ha/year.

In other crops, ground cover may be poor due to the lack of re-growth and the time of year of the harvest operation. Cultivation costs would be applicable after the main cultivation of the field. These would be some £17.50/ha plus £50/ha average cost for the seed, a total of £67.50/ha. (Cuttle, et all, 2007)

2.2.2.2 Catch Crops

Catch crops help to reduce the mobilisation of agricultural pollutants by increasing nutrient uptake and reducing surface run-off and soil erosion. Catch crops are fast-growing crops that are grown simultaneously with or between successive plantings of a main crop.

Effect analysis

Primary Effect

Catch crops protect the surface of the soil and catch the extra nutrients. The longer the soil is covered with vegetation the smaller is the nitrate leaching. Catch crops can also improve the soil structure and increase the amount of organic matter in the soil.

Water-related side effects

Plant cover in winter protects the topsoil of the fields against the erosive forces of rain, melt and runoff waters during winters. This also reduces soil erosion into waters.

Non-water-related side effects

Despite the effective reducing of nitrate leaching risk, some catch crops (e.g. mustard) can lead to a decrease in nitrogen uptake by following cereals (Möller, et al, 2007).

Geographical scale of the effect

☑ local ☑ regional ☐ Basin- wide

Time scale

Durability of an effect:

As long as applied

Adaptability

High

Certainty of the effect

High

Costs

This method is relatively easy to implement. The costs of this method consist of buying the seeds, sowing and finishing the catch crop. Danish estimates show that catch crops reduce the economic rent from cash crops by about 10 percent (Schou, J.S, et al., 2006)

2.2.2.3 Erosion-minimising Cultivation Systems

Erosion-minising cultivation systems incorporate discs or tines to cultivate the soil or drill directly into stubbles (no-till), thus maintaining organic matter and preserving good soil structure. This will improve infiltration and retention of water and thereby decrease total phosphorus concentrations in surface run-off.

Effect analysis

Primary Effect

Such cultivation systems will decrease phosphorus in surface run-off, as phosphorus then concentrates in the shallow topsoil, which can increase the amount of dissolved phosphorus in the long term. This is especially valid in areas containing steep slopes with high phosphorus content. To increase effectiveness of this measure, buffer zones and more accurate phosphorus fertilization should be utilised. With respect to nitrogen, nitrate leaching is slightly decreased through reduced mineralization of organic soil matter in the autumn.

Water-related side effects

Not known

Non-water-related side effects

Not known

Geographical scale of the effect

☑ local ☑ regional ☑ Basin- wide

Time scale

Until implementation:	short-term
Until effectiveness:	The measures may become effective in the short-term, as well as in the medium- or long-term, depending on the regional peculiarities (Interwies et al, 2004)

Durability of an effect:

As long as applied.

Adaptability

High

Certainty of the effect

The method must be used with judgement. It is less universally applicable on light soils and those which are liable to capping or compaction. Inappropriate use of the technique could cause more harm than benefit, due to soil damage, resultant poor crop growth and enhanced surface runoff in areas prone to capping.

Costs

The costs of this method are dependant on the suitability of a farm's crop rotation method, the soil type and whether it is profitable to use a contractor or purchase the machinery to the farm.

In cases where mulch sowing can be done with existing equipment, by definition no additional costs are incurred. Due to the reduced amount of time and petrol needed compared with conventional techniques, the costs may in fact be reduced in some cases.

2.2.3 Fertilizer and Manure Management

2.2.3.1 Nutrient Balances

The preparation of nutrient balances is a beneficial tool for long-term planning of fertilizer use. Nutrient balances inform farmers on the efficiency of nutrient utilization and help to identify the cropping phases in which nutrients are lost. The calculation of nutrient balances help to strengthen water protection measures for each farm and parcel.

Effect analysis

Primary Effect

Creating a nutrient balance spread sheet helps to accurately account for fertilizer use to decrease application, which in turn helps to keep excess nutrients in the soil to a minimum. It also maximises efficient use of nutrients already in the soil by ensuring that the soil is in a sufficiently fertile state I. Accurate fertilizer application, which is based on the crop type, its yield and the characteristics of the parcel to the economic optimum, will ensure that the necessary quantities of the essential crop nutrients are only available when required for uptake by the crop.

Example UK:

For arable land, there is a reduction of about 5 kg N/ha leached per year. For grassland, reductions are 1-5 kg/ha per year (dairy) and 2 kg N/ha per year (beef). With respect to P, expert analysis estimates that the method reduces the fertiliser component of the baseline loss by 20% (Cuttle et al (2007).

Water-related side effects

By reducing nutrient application due to nutrient balance analysis, eutrophication and excessive algal growths caused by nutrient leaching from fields can be minimised or avoided. Additionally, groundwater (used for drinking water supplies) contamination resulting from high nitrate content can also be minimised or avoided.

Non-water-related side effects

As nutrient management systems incorporating nutrient balances encourage efficient use of manure, there is a good possibility that ammonia emissions into air can be reduced.

Geographical scale of the effect

☑ local ☑ regional ☑ Basin- wide

Time scale

Until implementation:	Short-term
Until effectiveness:	Short term once farmers complete their nutrient balance analysis.

Durability of an effect:

As long as a farmer carries out such balances and take the appropriate decision afterwards.

Adaptability

Fertiliser recommendation systems can be used in all farming systems, but are most effective in intensive grassland, arable and horticultural systems. The method would have less impact in extensive grassland systems, since such systems tend to receive less N input than other systems do.

Certainty of the effect

Depends on the accuracy of the calculation and if the results are considered in farm management.

Costs

This method is cost-effective. Reduction in fertilizer application reduces farm costs; however, investment will be required to provide farmers with education and guidance.

Example from Scotland

In 2002 the Scottish Environment Protection Agency (SEPA) commissioned a study looking at agricultural environmental management on six different farm types. Based on the results of the study, which showed excess fertilizer and manure use on all farms analysed, farmers can save on average £1500 a year on fertiliser bills through better accounting of soil and organic nutrients. (SEPA, 2005)

2.2.3.2 Application Techniques of Manure

This measure involves cutting slots in the soils, injecting the slurry and then closing these slots after application. Injecting slurry as opposed to applying it to topsoil makes it is possible to directly reach the active soil layer in order to reduce nutrient leaching. In addition, direct ground injection systems directly inject pressurized slurry into the ground.

Effect analysis

Primary Effect

The injection of slurry effectively increases the utilization of manure nutrients compared with surface application, thus reducing potential run-off and need for more application. However it should be noted that most of the emission reduction ion water occur due to decreased deposition of ammonium. So the direct effect on water is rather low, while the indirect effect can be considered as high.

Water-related side effects

Decreasing surface application of manure and promoting injection techniques and mulching will immediately decrease leaching into water bodies as well prevent the exposure of manure to the surface run-off and drain flow losses.

Eutrophication resulting from emissions can be avoided by applying manure more effectively into the soil. Reduced groundwater and surface water pollution from nitrate leaching and phosphate run off.

Non-water-related side effects

Using trailing hose technology for slurry application can reduce emissions (ammonia) into air significantly.

Geographical scale of the effect

☑ local ☑ regional ☐ Basin- wide

Time scale

Until implementation: Short-term

Until effectiveness: Short term

Durability of an effect:

As long as farmers applies the measure and machinery is in a good shape.

Adaptability

Steeply sloping ground or stony soils may not suitable for slurry injection, as these soils can cause increased nitrate leaching and watercourse pollution.

Certainty of the effect

Medium as there are limitation in the application of the measures (see adaptability above)

Costs

Costs associated with better application technology can be high (Replacing manure spreading equipment is a major capital investment), but costs can be saved through reduction in mineral nitrogen application.

2.2.3.3 Integration of Fertilizer and Manure Nutrient Supply

Determining the amount of nutrients supplied to soils during manure application helps farmers to judge the amount and ideal timing of additional fertilizers required by the crop. Taking better account of the nutrients contained manure can reduce the need for fertilizer inputs, which in turn minimises nitrate and phosphorus losses.

Effect analysis

Primary Effect

Excessive application of mineral fertilizer applications is avoided, so optimum economic production level can be reached and soils can be adequately maintained. The method is most effective on farmers where manure is supplemented by mineral fertilizers.

Water-related side effects

Reduced nitrogen and phosphorus leaching can be expected from this measure, as less N and P are applied to land.

Non-water-related side effects

Long-term manure applications can lead to a build up of excessive soil P reserves. By integrating fertilizer and manure application, dentrification, which leads to increased levels of nitrogen oxide emissions, can be minimised as a result of proper scheduling.

Geographical scale of the effect

☑ local ☑ regional ☑ Basin- wide

Time scale

Until implementation: Short-term

Until effectiveness: Short term

Durability of an effect:

As long as farmers applies the measure

Adaptability

This measure is most applicable to intensive grassland and arable systems, but is also relevant to extensive grassland systems where breeding ewes are brought onto more fertile low-lying ground in late autumn to early winter. Additionally, this method is effective for systems that use mineral fertilisers to top-up nutrients supplied by organic manure.

Certainty of the effect

On arable land, there ia potential for a reduction in N leaching by 5-10 kg/year (Cuttle et al (2007).

Costs

This method achieves savings rather than incurring costs; however investment will be required for education and guidance.

2.2.3.4 Avoiding the application of Fertilizers and Manure to High-Risk Areas

Never applying mineral fertilizers and manure to high risk areas helps to prevent run-off of nitrate and phosphorus in the watercourses. Risk areas include areas with flushes draining to a nearby watercourse, cracked soils over field drain or fields with high phosphorus number (Helsinki Commission, 2007). To determine Phosphorus risk areas, a risk index or specific risk factors can be used.

Effect analysis

Primary Effect

Areas with a high phosphorus index have a significant risk of losing P through eroded soil particles and by leaching. Applying manure to these areas will increase the excessive phosphorus content of the soil and increase the amounts lost. This method is most effective against losses of phosphorus where the primary mechanism of transport is surface run-off.

Water-related side effects

High risk areas are field areas with direct flow paths to watercourses. A reduction or complete avoidance of manure application in such areas reduces the risk of manure or fertiliser draining into field drains and transporting pollutants into surface or groundwater. Further, the method also allows for a reduction in ammonium-N losses and nitrous oxide emissions.

Non-water-related side effects

On those farms that usually have a high rate of P use and spread manure on the same fields, the soils may have a high P index and should thus be excluded from receiving further applications. In these circumstances, it may be necessary to export surplus manure to other farms. Transportation may thus increase and concerns related to biosecurity may arise.

Geographical scale of the effect

☑ local ☑ regional ☐ Basin- wide

Time scale

Until implementation:	short-term
Until effectiveness:	The time scale required for the measure to take effect will vary greatly according to the P content already in the soils, the type of soil and its erosion rate, and rainfall patterns.

Durability of an effect:

As long as farmers applies the measure and machinery is in a good shape.

Adaptability

This method is potentially applicable to all farms applying manure that are directly adjacent to watercourses or in areas with risks of field drains. It may be most applicable to the extensive grassland sector, where open drains are common. (UK manual, 49)

Certainty of the effect

The certainty of the effect depends on a set of local factors, soil consistency playing a major role

Costs

Applying this measure could reduce crop yield and thus production potential, so costs can be seen in terms of income loss. Additionally, if there is a need to increase manure storage, there will be additional construction costs. However, no costs may be incurred if ground is available elsewhere on the farm.

2.2.3.5 Avoiding spreading Fertilizers and Manure at High-Risk times

By avoiding the spreading of mineral fertilizers or manure at high risk times, the nitrate leaching and loss of phosphorus through surface run off is diminished. High risk times include when there is a high risk of surface flow, rapid movement to field drains from wet soils or when there is little or not crop uptake. The measure requires adequate collection and storage facilities.

Effect analysis

Primary Effect

Surface run off poses the greatest risk in slope areas that are saturated, frozen or snow covered soils. Rapid flow of nutrients through the soil is most likely to occur from drained soils when they are wet and rainfall follows soon after applying fertilizers. A way to avoid leaching in the winter due to rainfall is to apply nitrogen in the autumn. Estimates expect a reduction of the P baseline losses of 50% on the sandy loam and 20% on clay loam soil (Cuttle et al, 2007)

Water-related side effects

In case of inappropriate storage or leakages point pollution might occur.

Non-water-related side effects

Storage can lead to some increases in ammonia and methane emissions, so minimum specifications are required to reduce such losses.

The method may limit opportunities for manure application before some spring crop are sown.

Geographical scale of the effect

☑ local ☑ regional ☐ Basin- wide

Time scale

Until implementation: Short- to medium-term

Until effectiveness: Medium- to long-term

Durability of an effect:

As long as farmers applies the measure and machinery is in a good shape.

Adaptability

The method is particularly relevant to livestock farms with limited manure storage facilities. Adequate storage facilities are most important on those farms that produce dirty water or handle their manure as slurry. Solid manure however can be stored in field heaps, or sometimes in the animal house until it is spread at a period presenting little or less risk of pollution.

Education and advisory activities may be necessary to convince farmers that they should not spread fertilisers and manure at high risk times.

Certainty of the effect

High

Costs

Livestock and dairy farms will face costs to handle and store the manure appropriately. Costs associated with increasing manure storage capabilities include general construction costs, soil quality, regulations on manure storage etc. In the Netherlands, for example, costs for manure storage is estimated at USD$50 per cubic meter[4]. In Poland the construction costs (excluding VAT) for a dung plate are between 28 and 39 Euros per m2 and for fully under the ground level covered tanks (for slurry and dung water storage) between 103 and 122 Euros per m2[5].

2.2.3.6 Transporting Manure to Neighbouring Farms

Farms with manure surpluses can avoid the need to increase storage capacity be exporting the surplus to neighbouring farmland. This reduces the nutrient load on the farm that has an excess of manure thereby reducing the risk of diffuse pollution. It also enables the remaining manure to be managed in a more integrated way.

Effect analysis

Primary Effect

Farms with soils that have high N rates or are located in high risk zones (close to watercourses) transport their excessive organic manures to other farms. This reduces the pressure to apply manure during high risk periods, thus restricting the nutrient load on the farm site and the risk of diffuse pollution. The input of nutrients is balanced and the land is given enough capacity to absorb the nutrients

Water-related side effects

In the case of contaminated manure (e.g. heavy metals, pathogens) pollution might be spread

Non-water-related side effects

This method results in increased transportation, which can be linked to potential odour emissions associated with the transport of manure and increased concerns about biosecurity.

Geographical scale of the effect

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[4] http://lead.virtualcentre.org/en/dec/toolbox/Tech/21Mansto.htm

[5] http://www.baap.lt/nitrate/poland/chap_3.htm

☑ local ☑ regional ☐ Basin- wide

Time scale

Until implementation: Medium to long-term, depending on the political constraints

Until effectiveness: Medium- to long-term

Durability of an effect:

As long a critical mass of farmers takes place in such a system.

Adaptability

The method is most easily applied where receiving farms are close. These must also have the land capacity to absorb the transported organic N (and P) load

Certainty of the effect

Medium to High, depending on farmers participation.

Costs

This method is easiest applied when the receiving farm holding is close, that is within 5-20 km. Costs increase with distance. Composting manure before transporting over long distances increases transportation ease.

2.2.3.7 Slurry Separation

Slurry separation divides slurry into liquid and solid components. The liquid part contains lower nutrient concentration and is able to be used at the production site. The solid component is made up of high dry matter content and high nutrient concentration and can be transported to the other farms. This can either be done slowly by a weeping wall system or more quickly by mechanical separation. There are a number of different types of mechanical separators including rotary screens, roller presses, screw presses, inclined screens and vibrating screens.

Effect analysis

Primary Effect

Although slurry separation does not change the total phosphorus content of the slurry, it will help to decrease the cost of transportation to other areas when there is not enough arable land to spread the slurry. Slurry separation provides for greater flexibility in spreading times and application and thus can optimize the full nutrient potential of slurry.

Water-related side effects

Not known

Non-water-related side effects

Potential reduction in slurry storage capacity requirements.

Geographical scale of the effect

☑ local ☑ regional ☐ Basin- wide

Time scale

Until implementation: Short-term
Until effectiveness: Short term

Durability of an effect:

As long as farmers applies the measure and machinery is in a good shape.

Adaptability

High, several technical solutions are available.

Certainty of the effect

High

Costs

Slurry separation requires equipment for the separation process, the separate storing and the spreading. This can represent an important burden for the farmer in terms of space and/or costs.

2.2.4 Animal Feeding

2.2.4.1 Optimization of Animal Nutrition

The optimization of animal manure is not directly linked to water protection. It reduces the pressure only in cases where animal manure is applied on the field again. Due to the increasing demand of bioenergy this measure might be replaced in the future by increasing biogas production from manure (Dworak, et al 2007)

The most effective measure to reduce nitrogen content in animal manure is the adjustment, in terms of N, of the protein supply to the nutritional demand of cattle, pigs and poultry. With a consistent N-adjusted feeding regime for pig fattening, sow keeping and poultry fattening nitrogen excretion is reduced and the nitrogen content in the manure is limited.

Further, supplementation of synthetic phytase (which is a microbially produced enzyme) to pig feed reduces the need for addition of mineral phosphate. Phytase increases the availability of phosphorus in the feed and allows total phosphorus contents to be reduced without affecting productivity.

Effect analysis

Primary Effect

The potential for reducing nutrient excretion with an N-adjusted feeding regime varies between 5 and 40 %, depending on animal species, performance and the initial situation

(Döler, et al. 2002, Gronauer 2002, Hartung 2002). The effects of reduction are determined by how frequently the N is adjusted during the fattening period (two, three or multi-phase feeding), or in sow keeping (two phase feeding: lactation and pregnancy) and by the proportion of the amino acids added.

The resulting reduction of P excreted during pig and poultry production from the above-mentioned measures ranges between 30% (Helcom, Comission, 2007) and 70 % (Umweltbundesamt, 2004)

Example : Denmark

Jacobsen et al. (2004) investigated the countrywide economic effects of different measures in Denmark. The most effective measure is through a change in feeding practices (increase use of phytase and use of phase feeding). According to the authors this measure, which will reduce total P surplus by more than 40%, is almost cost neutral. A further measure is a nationwide norm that limits the phosphorous surplus to 10 kg per ha (and thereby reduce the surplus by 25% on average). If implemented after the change in feeding practice, this would mean that 5 % of all manure would need to be redistributed, affecting intensive dairy and poultry farms in particular. This would increase the transportation costs by 2.4 million Euro in total. From this, cost savings on P in mineral fertiliser of 2.3 million Euro have to be subtracted, so that the net costs are relatively low. As a third measure, achieving a balance between incoming and outgoing phosphorus at the farm level is expected to cost around 47 million Euro. This measure would also lead to substantial redistribution of animal manure between parts of the country. However, the authors also underline that these calculations represent rough estimates only, and should therefore be treated with caution.

Water-related side effects

Not known

Non-water-related side effects

If there is too little phosphorus in the pig feed or the ratio between different minerals is wrong, the condition of pig legs and the ability to move can weaken. This can have an effect on the economical output.

The reduction of nitrogen in animal manure leads to a reduction in the emission of ammonia.

Geographical scale of the effect

☑ local ☐ regional ☐ Basin- wide

Time scale

Until implementation: short-term

Until effectiveness: short-term

Durability of an effect:

Requires continuous application

Adaptability

High. When new scientific knowledge, new products and feeding techniques is available it can be introduced easily.

Certainty of the effect

High

Costs

The implementation of phased feeding requires the appropriate technical equipment on the farm. Costs arise for this additional feeding technology, although costs for the raw protein in feed can be reduced. Depending on the implementation of the phased feeding (two or multi-phase feeding) and the size of the farm, these costs could be balanced for a farm with many animals. (Umweltbundesamt, 2004)

2.2.5 Farm Infrastructure

2.2.5.1 Buffer Zones

Establishing vegetated and unfertilized buffer zones alongside watercourses decreases erosion and the movement of nutrients into watercourses. Buffer zones can reduce pollution by changing land use (i.e. they stop agricultural activity on the area), there by reducing direct pollution from inorganic fertilizers and organic manure additions. They also act as a shield against overland flow from agricultural area and prevent run-off to reach the watercourse.

Effect analysis

Primary Effect

The potential of this measure is dependent on the establishment of buffer stripes along watercourses and the corresponding distance requirement and use restrictions by the executive of the state or within the framework of agri-environmental programs. The filtering effect with respect to nutrient flows into the surface waters is expected to be low and therefore the contribution of this measure to reduce pollution is not expected to be high. This is because the structure and width of the margins are usually insufficient for effective filtering and because the topography alongside only a few surface waters allows for a filtering function by the vegetation on the bank anyway (DVWK 1995). A quantitative assessment of this reduction measure is not possible. The efficiency of buffer zones in removing suspended solids and nutrients is affected by the width of the zone, gradient of the drained field, soil type and particularly by the variety and density of zone vegetation (Wenger, 1999).

Water-related side effects

Further scientific research has shown that vegetative buffers are effective at trapping sediment from runoff and at reducing channel erosion. Buffers, as narrow as 4.6 m (15 ft) have proven fairly effective in the short term. Although wider buffers provide greater sediment control, especially on steeper slopes. Long-term studies suggest the need for much wider buffers (30 m). Further the protection against pesticides and heavy metals is judged to be very positive (Wenger, 1999).

Non-water-related side effects

- buffer stripes form structural element in the landscape and maintain the cross linking of biotopes
- Reduced yields due to a reduction in usable agricultural land and due to shading.

Geographical scale of the effect

☑ local ☑ regional ☐ Basin-wide

Time scale

Until implementation:	Short- to long-term (depending on the availability of land)
Until effectiveness:	short to medium-term (depending on the vegetation planted)

Durability of an effect:

See: Certainty of the effect

Adaptability

High

Certainty of the effect

Buffers are short-term sinks for phosphorus, but over the long term their effectiveness is limited. Buffers can provide very good control of nitrogen, include nitrate but widths necessary for reducing nitrate concentrations vary based on local hydrology, soil factors, slope and other variables. Wenger, 1999 refers to a width between 15 and 30 m, which is often impossible to implement in agricultural areas.

Costs

Buffer zones require a certain amount of investments to establishment but once established require little maintenance.

Example from Germany:

Land purchase for Agricultural areas: ~30 €/m² (range up to 4.00 €/m²) and for conurbation areas: Agriculturally used land > 5.00 €/m² (Umweltbundesamt, 1999)

Plant copse barrier: Plant alders at suitable locations: 13.50 €/each (3 per linear m) Umweltbundesamt,1999)

Maintenance: ~ 1.60 €/m * a (IGuG 2001)

2.2.6 Education and Training

2.2.6.1 Systematic On-Farm Individual Advice

Agri-environmental measures are implemented by close co-operation between farmers and advisors. Advisory services can lead to reducing stocking density, crop coverage over winter, intercropping, fixed value for nitrogen utilization of farm manure, limited nutrient budget, fertilizer plans and nutrient balances.

Effect analysis

Method can be used to enforce measures mentioned above. So no direct effect can be estimated.

Geographical scale of the effect

☑ local ☑ regional ☑ Basin- wide

Time scale

Until implementation:	Short- to medium-term
Until effectiveness:	Medium-term

Durability of an effect:

This is strongly depending on the farmer's willingness.

Adaptability

High, as each training can be adapted to regional circumstances and needs of the farmers

Certainty of the effect

The Certainty of the effect depends strongly on the willingness of the participating farmers to implement the trained issues. It can be low to high.

Costs

Costs depend on the salary of the lectors and/or the support given to farmers to participate.

Example from Austria:

For Austria the cost for a one day training to 15 farmers are estimated to be 1.200 Euros (Bundesamt für Wasserwirtschaft, WPA, 2007 unpublished)

2.2.7 Selection of measures – Final remarks

As one can see from the above list of measures quantifying costs and effects of these measures is a difficult task. Currently several EU Member States and the EU Commission are working to implement cost-effectiveness analysis for agricultural measures but the approaches and the existing data and methodologies are varying widely. It clearly appears that there is no common approach for integrated cost-effectiveness analysis for agricultural measures. Further information on costs varies widely and the effectiveness of a measure often depends on local natural conditions.

Even if there are a lot of uncertainty and data gaps, there is enough knowledge to take action in the Black Sea region. The most important action to be taken is the development and establishment of a commonly agreed "good agricultural practice" (GAP)[6]. Such agreed GAP should be set as minimum a baseline (a "red line") of environmental standards and should include the following issues:

- Focus on closed nutrient cycles and environmental friendly application of fertilizer and manure. This includes:
    - Appropriate application rates: The amount of plant nutrients to be applied in the form of mineral fertilizers has to be calculated each year to ensure that it matches the nutrient requirements of the crop. This requires carrying out nutrient balances on a regular basis Cop residues and animal manure should be used first. In environmentally sensitive areas standard practices may need to be modified and restricted.
    - Correct time of application: Depending on crop variety, planting date and the crop rotation, as well as on external factors such as soil type and local weather conditions the amount and timing of nutrient uptake by the crop varies. Nitrogen fertilizers should not be applied in high risk times..
    - Suitable type of fertilizer: Selecting the type of fertilizer to be used should include an assessment of likely environmental impact and agronomic efficiency. Both chemical form and physical characteristics are important. The choice of fertilizer and chemical form of the nutrient components depends on the chemical properties and analysis of the soil and the nutritional requirements and physiological sensitivities of the crop.

  However it should be noted that not all aspects of BAP will be relevant in all DRB countries. The detailed implementation of the BAP should be viewed as a broad spectrum of measures that can be interpreted according to local environmental, social and economic circumstances.
- Limitations of the intensity of agricultural production to limit future pollution due to increasing economic growth;
- In order to reduce point pollution from agriculture large animal farms are point sources which should be subject to legislation for industry (e.g. IPPC-Directive) (see also UNDP/GEF Danube Regional Project, 2003);
- Regularly training and education measures.

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[6] Please note that all EU Member states had to develop such GAP under the Nitrate Directive. An example for some Black Sea countries can be found http://www.bseanetwork.org/pdf/GoodAgriculturalPractice-DRPII-21728.pdf

3 Case study on nutrient reduction in the municipal sector

This task aims to evaluate the cost effectiveness of different upgrading options in municipal sewage treatment works. The evaluation will also consider the impact of policies e.g. the compulsory introduction of P-free or reduced-P detergents on the cost effectiveness.

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 p.e. 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 be applied depending on the local situation. The values for concentration or for the percentage of reduction shall apply. 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.

3.1 Overview of requirements according UWWTD

agglomerations > 2,000 pe: secondary treatment (C-removal)

agglomerations 10,000 – 100,000 pe, sensitive areas:
Ntot: 15 mg/l or 70 - 80 % min. percentage of red.
Ptot: 2 mg/l or 80 % min. percentage of red.

agglomerations > 100,000 pe, sensitive areas:
Ntot: 10 mg/l or 70 - 80 % min. percentage of red.
Ptot: 1 mg/l or 80 % min. percentage of red.

The use of UWWT-Directive standards is used for demonstration purposes only. 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, so can the discharge standards be adapted. The methodology presented in section 3.2 will, therefore, require modification to be used in these countries.

Cost effectiveness in waste water treatment is assessed as ratio of costs of the additional treatment process (nitrification/denitrification; P-precipitation) versus the obtained additional emission reduction. Selected "side effects" like the removal of micropollutants (Clara et al. 2005) or the potential improvement of groundwater as a result of measures in waste water management (especially regions that are connected to sewer systems) will be discussed only in a qualitative manner.

The cost effectiveness analysis will be carried out in two main steps:

- estimations of emissions reduced for different treatment levels: C-removal (C-plants), C-removal + nitrification (CN-plants, C-removal + nitrification + denitrification (CND-plants), C-removal + P removal (CP-plants) and C-removal + nitrification + denitrification + P removal (CNDP-plants)

- costs of different upgrading options in municipal sewage treatment works; the costs will consider effects of the "economy of scale" (dependency of costs on the design capacity of the plant).

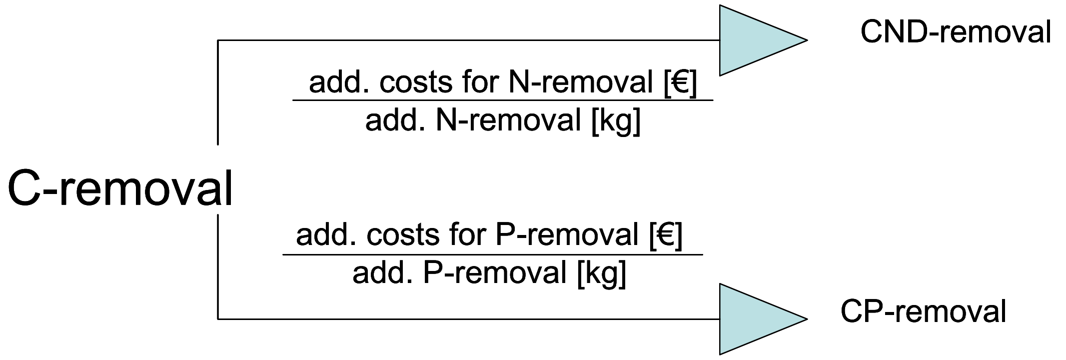

Figure 2: Framework for cost effectiveness in the UWWTD sector

The general approach will be as follows: Existing cost functions for annual capital costs as well as operation costs for ("western") treatment plants will be adapted for several countries in the Black Sea catchment using "local"/national data. Case studies in the countries will support the derivation of the cost functions.

For the case study-plants, information originally provided to support the upgrading of municipal waste water treatment plants should be used. The selected case studies should meet one of the following criteria: (i) "new" waste water treatment plant, (ii) recently upgraded plant or (iii) plant which will be upgraded soon. Data was gathered via questionnaires. The detailed questionnaires developed are enclosed in the Annex. A translation of the questionnaire into Russian language was carried out.

In the questionnaire two different types of information were requested:

1) general "national" information which is not plant specific, e.g. labour costs per month, price of electricity, costs of precipitants, effluent standards in the country, etc.

2) specific data including economic data (operation costs, investment costs) of the case study plant. An important part of information is also the costs of sludge management (disposal charges, etc.) (this information is partly plant specific but probably regulations on a national level exist).

It has to be expected that not all (detailed) information requested will be delivered. However the more local and national data will be obtained, the more the results are reflecting the specific national situation.

Up to now contacts to treatment plants in Ukraine, Romania and Bulgaria have been established. For four Hungarian treatment plants data was provided from the Technical University of Budapest. A further case study is foreseen for the Czech Republic.

3.1.1 Short description of C, CND and CNDP plants

In our investigations only single stage activated sludge systems are considered as they are commonly used worldwide. In Europe it is the prevalent system.

C-plants are designed for Carbon removal (= organic matter removal) only. Usually they consist of an aeration tank and a subsequent settling tank. In the SBR-type (Sequencing

Batch Reactor) aeration and settling take place in the same tank.

CND plants: Two systems are commonly used: (a) activated sludge without primary settling and with simultaneous aerobic sludge stabilisation and (b) activated sludge with primary settling and with anaerobic sludge stabilisation. Nitrogen removal is achieved via a nitrification step (biological conversion of Ammonium to Nitrate) in the aerobic zone and a subsequent dentrification step (biological conversion of Nitrate into molecular Nitrogen) in anoxic zones of the aeration tank. In the SBR-type aeration, nitrification/denitrification and settling take place in the same tank.

a) This system usually is applied for small(er) plants (up to 100000 pe) as the use of biogas only becomes economically advantageous at plants > 50000 pe. The sludge stabilisation takes place simultaneously in the aeration tank. The stabilisation is achieved due to a high sludge age (25 days). A high sludge age requires a larger volume of the aeration tank. These plants do not have a primary sedimentation as this would produce unstabilised sludge. Due to the high sludge age high N-removal efficiencies exceeding 90% can be achieved. Usually effluent concentration of Nitrate < 2mg/l and Ammonia of <1 mg/l can be reached, exceeding by far the legal requirements for effluent quality. Especially during winter time sludge is not well stabilised.

b) The sludge stabilisation takes place in an anaerobic digester producing biogas that can be used for electricity and heat production. The sludge age (10-13 days) is considerably lower compared to simultaneous aerobic stabilisation system requiring less aeration tank volume (minus 1/3 to minus 50%). On the other side additional investments are necessary for the primary settling, the sludge digestion, the biogas collection and the cogeneration unit. A removal efficiency for Nitrogen up to 80% can be achieved as by primary settling the removal efficiency for organic substances is higher than for nitrogenous compounds which results in lower DN capacities.

CNDP plants: these plants have in addition to the N-removal described above a P-removal step. Usually the P-removal is achieved by adding precipitants (e.g. Fe-salts, Al-salts) depending on the plant to the influent of the primary settling (pre-precipitation) and/or in the secondary treatment tank or to the activated sludge circle (simultaneous precipitation). Chemical precipitation can be combined with enhanced biological P-removal by luxury uptake, which reduces costs for chemicals especially during summertime.

3.2 Assessment of cost

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. However, these cost-functions are strongly influenced by national characteristics (salaries, price for electricity, charges for sludge disposal, etc.) and therefore have to be adapted to the local situation.

The collection of non-monetary data helps to compare cost data over national borders (manhours, energy consumption, chemicals consumption, etc.)

Cost functions show the effect of “economy of scale”. This effect also will be considered in the adaptation of the cost functions.

The approach in respect to the main assumptions of the assessment will be as follows:

- the configurations and operation schemes of treatment plants in other countries fulfilling certain emission requirements (C-removal only, C+N-removal, C+P-removal, C+P+N-removal) are similar to those included in the studies on cost functions which will be adapted. This implies also, that the productivity of labour, the efficiency of aeration, etc. is comparable.

- Cost functions for investment costs and operation costs will be split up to several cost categories
- From the cost categories the non-cost-information will be derived (e.g.: from the amount of personnel cost the number of person month will be calculated).
- Combination of the non-cost-information with local prices/salaries to obtain local cost functions
- Finally the case study results will be compared with the local cost functions derived

In the following sections investment costs as well as operation costs will be discussed.

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 such as maintenance probably are related to the physical size of the plant and the number of tanks and pieces of machinery it is composed of.

3.2.1 Investment costs (annual capital costs)

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.

It is not possible to use purchasing power parity exchange rate (PPP) to “translate” costs from one country to another as this rate compares the standard of living based on predefined baskets of goods.

Investment costs can be split up into costs of construction and to 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 as depicted in the following diagram (adapted from (Kroiss et al. 2001)).

Out of the construction and machinery/electrical installation costs 20% (Lindtner, 2007) to 30% (Nowak 1999) are due to the biological treatment (primary settling, aeration tank, clarifier). Out of this 60% (C-plants) to 70% (CND-plants) of the costs can be attributed to the aeration tank.

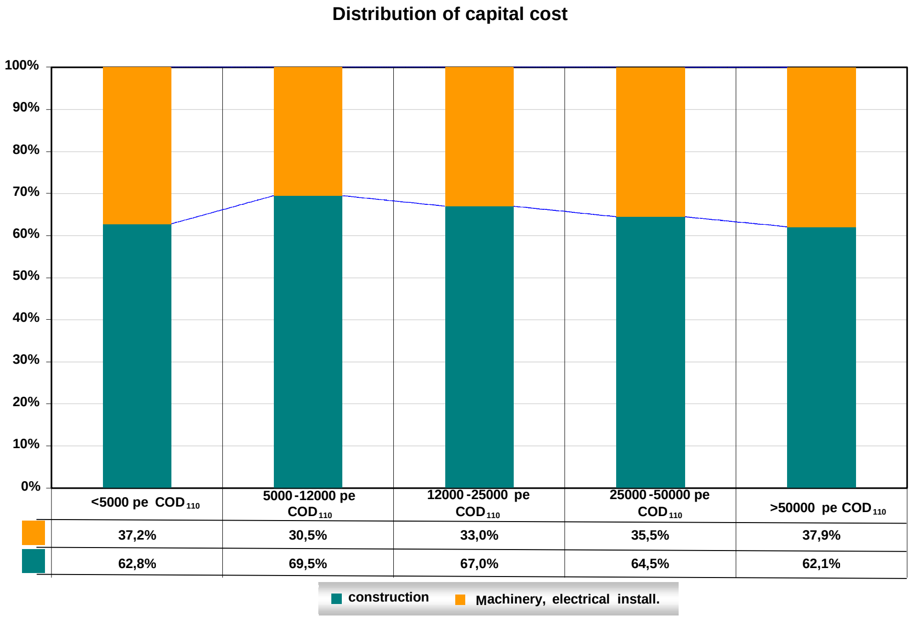

Figure 3: Distribution of annual capital costs depending on the size of the treatment plant (adapted from (Kroiss et al. 2001))

It can be concluded that there is no significant dependency of the size of the treatment plants on the distribution of annual capital costs in Austria.

Assumption for the calculations: 65% of the annual capital costs are due to construction costs

Investment costs (construction as well as machinery and electrical installations) result from "salaries" and "other costs" like costs of machinery, materials, etc. If a distinction of these two categories would be possible, an adaptation of investment costs to "local" prices could be done. However information in literature on this item is very scarce. In (Flögl, 1980) the following ratio was given: 60% salaries, 40% other costs (range: 55:45 – 65:35). This would indicate that construction costs in countries with low salaries probably would cause significant lower construction costs.

According data presented in (Statistisches Bundesamt 2007) for German enterprises the share of relation of personnel costs : material costs can be calculated as follows:

- structural and civil engineering: 56%: 44%
- subsector electrical installations: 52% :48%
- subsector of gas-, water-, heating and aeration installations: 45% : 55%

From (Nowak, 1999) the cost-ratio of 30% electric installation and 70% machinery can be derived. For the machinery part the share of personnel costs for assembling were assumed with 20% for eastern countries (this share is about 30% in countries with high salaries (Escobar, 2007)).

Assumptions for the relations of personnel costs : material costs

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

These assumption meeting Austrian conditions are 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. The material costs are assumed as already mentioned to be as high as in Austria in all the other countries under investigation.

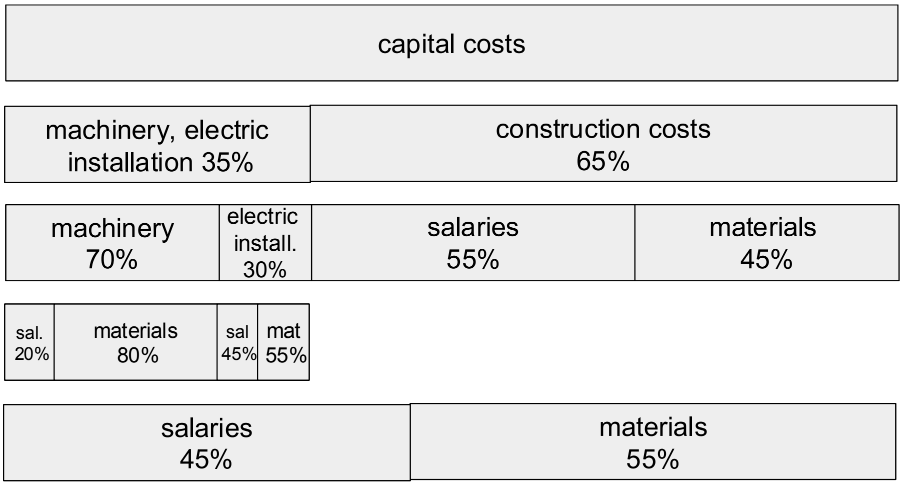

Figure 4: subdivision of annual capital costs

Wages/salaries in different professions vary considerably. The use of mean average incomes would overestimate the costs of the personnel in the construction sector or of the staff of waste water treatment plants. In various statistics only gross salaries are depicted which do not reflect the full costs of an employee.

For our estimations we used information on gross salaries in capital cities for construction workers and skilled workers provided by (UBS, 2007) assuming a mean value of these two categories. The employer's contribution was obtained from the German federal statistical office (Destatis, 2007).

Table 2: Annual salaries (€) of construction workers and skilled workers in 2006

salaries incl. empl. contr.	construction workers	skilled workers	employers contribution in%
Austria	23042	41252	23,88
Bulgaria	3473	5953	24,03
Czech Republic	10348	13377	26,2
Germany	26710	37637	21,41
Hungary	6365	9038	27,3
Romania	3249	5874	24,97
Slovakia	4950	10270	23,74
Slovenia	9284	14719	13,22

For Turkey and Ukraine no values were provided in the data base depicted above. For these two countries an internet investigation was carried out. The information obtained is quite heterogeneous. In general it can be said that the salaries compared to Bulgaria or Romania are lower in Ukraine and higher in Turkey. Finally the following annual salaries for the construction sector were assumed:

Table 3: Assumptions on salaries (€) in the construction sector in Turkey and Ukraine

	average salaries
Turkey	6000
Ukraine	2400

Case study results: in €/month

Ukrainian plant: staff wwtp: 150€/month, construction sector: 205 €/month

To reflect the development of wages/salaries the following assumption were made:

Investment costs: Current wages 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 4: Annual labour costs used for cost calculations in €/employee

€/year	A	BG	CZ	HU	RO	SK	SI	TK	UA
investment costs	32147	4713	11863	7702	4561	7610	12001	6000	2400
operation costs	32147	11572	16934	13813	11458	13744	17038	12537	9837

It should be noted that salaries within countries differ. As an example for Romania average regional salaries vary between 122% in Bucharest and 89% in the north-east (100% = Romanian average) (IHK Pfalz, 2007). Consequently the salaries depicted will denote somehow the upper limits as they were indicated for capital cities.

The labour productivity in the Black Sea catchment country differs considerably. Labour productivity is defined by the (OECD 2002) to be "the ratio of a volume measure of output to a volume measure of input". Volume measures of output are normally GDP or GVA (Gross Value Added), expressed at constant prices i.e. adjusted for inflation. The three most commonly used measures of input are: hours worked; workforce jobs; and number of people in employment.

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 (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 investment costs. It was assumed, that in 30 years the labour productivity will be the same in all countries under investigation. For the calculations we used the mean of the current difference and the future equality. e.g.: currently the labour productivity in Austria is 3.44 times higher compared to Bulgaria – in 30 years it will be equal (= 1) the resulting mean of “3.44” and “1” is “2.22” – this mean will be used for the calculations for Bulgaria. For investment costs the current differences in labour productivity were used.

Table 5: Labour productivity in countries under investigation

labour productivity	A*	BG*	CZ*	HU*	RO*	SK*	SI*	TK**	UA***
current % (A = 100)	100	29	58	61	31	58	68	34	20
Factor for investment costs	1	3,5	1,7	1,6	3,2	1,7	1,5	3,0	5,1
Factor for operation costs	1	2,2	1,4	1,3	2,1	1,4	1,2	2,0	3,1

* Eustat 2007; ** OECD 2006; *** ILO 2007

(EC Harris 2005) gives an overview of construction costs for “common types of buildings” of 35 countries worldwide in 2005. According these data construction costs are 30 to 50% lower in eastern countries compared to Austria. The values presented for Slovakia seem to be very low.

Table 6: construction costs in selected countries (own calculations based on data from EC Harris (2005)

	from	to	mean
Austria	85	115	100
Germany	80	106	93
Bulgaria	38	53	45
Croatia	50	76	63
Romania	41	70	56
Russia	63	78	70
Serbia&Montenegro	44	67	56
Slovakia	38	56	47
Czech Republic	68	75	71
Turkey	54	76	65

According to the expert judgement of an Austrian waste water consultant, the following general statements can be made for investment costs:

- The construction of treatment plants in Eastern Europe is somewhat cheaper. Especially formwork is considerably cheaper (less than 50%); formwork contributes up to 40% of the total construction costs.
- Prices for steel are comparable to Western Europe as steel is bought from the world market.
- Prices for concrete are comparable.
- The costs for assembling machinery at the plant are about 20% of the machinery costs itself. In countries with high wages the assembling costs increase up to 30%.
- Machinery usually is bought in western countries at the same prices.
- For Turkey the situation seems to be different. Often local companies are in charge providing lower prices. It is questionable if the quality of the constructions is comparable.
- often “western” consultants are planning the treatment plants, partly also western companies are erecting the treatment plants

According an expert judgement of an Austrian waste water consultant the following general statements can be made for operational costs:

- Operational costs are cheaper due to the low salaries
- Prices for precipitants are similar
- Prices for polymers are similar

3.2.1.1 Annual capital costs

In order to compare investment costs with annual operation costs, the investment costs have to be transferred into annual costs (annual capital costs).

Annual investment costs can be found from the total investment costs and a pay back time or return of investment time of X years = annuitization.

Annuitization:

Annual capital costs = investment * annuity factor

$$a = C_0 \frac{q^n (q-1)}{q^n - 1}$$

Where:

$q = i + 1$

a…	annual capital costs
C_0..	investment costs
i…	real interest rate
n...	number of years

In this study a real interest rate of 5% is used as asked by EU project proposals.

Investment costs show a clear impact of the economy of scale. As an example the investment costs of waste water treatment plants in Austria in 2004 are depicted below (means of 8 different capacity sizes from < 50 pe to >100,000 pe; in total 288 plants, all classes comprise at least 8 plants, 61 treatment plants larger than 5000 pe). Further the sizes of treatment plants are indicated where the emission standards according the UWWTD change.

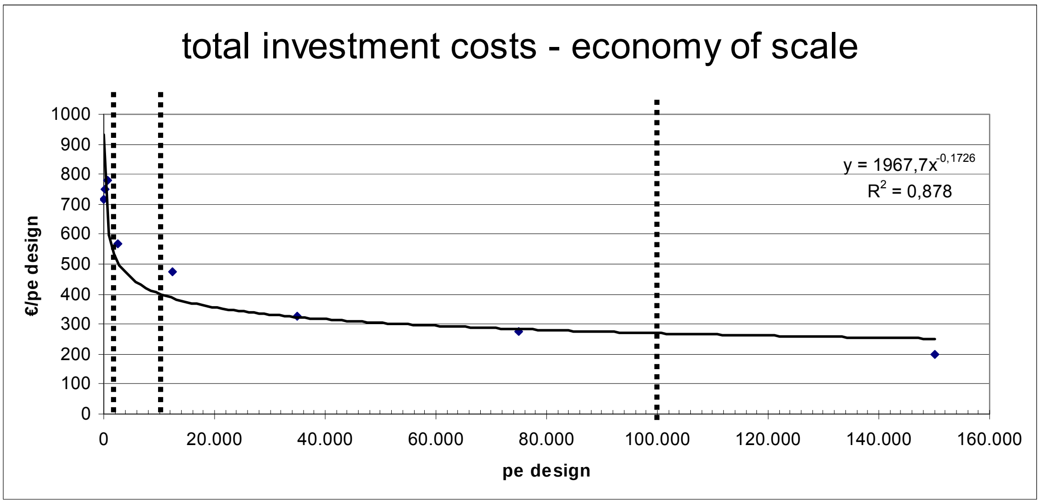

Figure 5: Investment costs of Austrian wwtps (P removal at plants > 1000 pe, N > 5000 pe)

The level of treatment influences the investment costs. For N-removal in addition to C-removal a nitrification/denitrification step is required. The denitrification step can take place in the same tank as the nitrification (simultaneous denitrification plant, alternating process), or in a separate tank (pre-denitrification). Nitrification (transformation of Ammonia to Nitrate) requires a higher sludge age, as the growth rate of nitrifying bacteria is low. A higher sludge age means that the volume of the biological treatment tank has to be enlarged. Further on nitrification has a considerable oxygen demand. N-removal by denitrification (transfer of Nitrate into N_2) needs additional volume. Compared to C-removal only nitrification and denitrification require larger aeration tanks. Secondary clarifiers, sludge treatment and disposal are nearly not affected by treatment efficiency.

- CND-Plants (C-removal, nitrification and denitrification) cause 1/3 higher construction costs of the aeration tank as plants with C-removal only.
- Denitrification requires additional volume of about 1/3 of the additional aeration tank volume for nitrification (of the aeration tank or alternatively of an additional tank).

- Additional expenditures for instrumentation and control technology and mechanical equipment occur for the aeration tank: + 1/4 of electrical and mechanical installation costs.

Table 7: 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

3.2.2 Operation costs

Operation costs can be subdivided into the following categories:

- Personnel costs
- Energy
- Maintenance
- Chemicals
- Sludge treatment and disposal
- discharge levies (if applicable)
- Other costs

It is not possible to directly transfer operation costs (or related shares of costs) obtained for treatment plants e.g. in Austria to many of the countries in the Black Sea catchment as prices and wages/salaries differ in a broad range. The methodology to overcome these problems (differences) is illustrated below. In addition several examples illustrating the differences are given.

In all cases the results of 29 Austrian case studies (plant sizes: 19 plants 20.000 – 50.000 pe, 4 plants 50.000 – 100.000 pe, 6 plants > 100.000 pe) are the base for calculations (reference year 2004).

According to the expert judgement of an Austrian waste water consultant, the following general statements can be made for investment costs:

- Operational costs are cheaper due to the low salaries
- Prices for precipitants are similar
- Prices for polymers are similar
- often “western” consultants are planning the treatment plants, partly also western companies are erecting the treatment plants
- Mechanical and electrical equipment and instrumentation and control often bought in “western” countries resulting in costs comparable to Western Europe.

3.2.2.1 Personnel costs

The costs for labour depend on the local/national salaries/wages.

Method:

1. Derivation of the number of employees of the plants from Austrian case studies: Annual personnel costs divided by average wages equals to person/years
2. Calculation of number of employees per population equivalent (resp. per actual pe)
3. Investigation of labour costs in the countries under investigation
4. Assumption on the increase of salaries during the next 30 years

Personnel costs are investigated in chapter 3.2.1 on investment costs.

3.2.2.2 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). Aeration is needed for C-removal (1.4 g O_2/gBOD$_5$ as well as for nitrification (4.3 g O_2/gN). 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 (1.5 g O_2/gN).

In numerous Austrian waste water treatment plants anaerobic stabilisation (sludge digestion) is applied. The biogas produced is processed in co-generation units (combined heating plants = CHP) and the energy content is transferred to heat as well as to electricity (typically 30% - 35% electricity, 50% - 55% heat, 10% - 15% losses). Counteracting additional investment costs for the co-generation unit accrue. Therefore it is not possible to use directly the costs for electricity as they reflect only the amount of electricity that is bought from external providers.

The consumption of mechanical energy and electricity per actual pe (kWh/pe) is a useful unit which can be transferred from one country to another (assuming similar treatment procedures). (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.

Method:

1. Evaluation of electricity consumption of the plants from Austrian case studies for plants with (i) carbon removal only, (ii) carbon removal plus nitrification, (iii) carbon removal plus nitrification and denitrification
2. Transfer of the electricity consumption to the actual loading of the plant
3. Investigation of electricity costs in the country under investigation

The costs for electricity depend on the local/national price for electricity, the tariff-structure, the type of sludge stabilisation, etc.

Prices of electricity in different countries vary considerably: Furthermore in some countries (like Bulgaria) different tariffs are offered - from 1-tariff reading (day and night electricity) to 3-tariff reading (peak electricity, day electricity, night electricity) with significant differences. The price of 100 kWh in 2007 in Bulgaria for industrial use 1-tariff reading amounts to 5.5€ (including VAT). Using a 2-tariff-reading the prices are 5.7€ for day electricity and 2.75€ for night electricity (SEWRC 2007).

In the following table mean values of electricity prices in 29 European countries (27 at that time member of the EU) for industrial consumers for the consumer type Ie (2000 MWh.y) are depicted (countries within the Danube Basin in bold letters).

Table 8: costs of electricity in €/100 kWh excluding VAT (stand 1.1.2007), price for industrial consumers, type Ie (2000 MWh.a) (Eurostat 2007)), *(EIA, 2007), **(Tsarenko, 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**	**9,32**	9,5	**9,4**	**3**

For Turkey (EIA, 2007) reports an electricity price of 0.1 US$/kWh.

In (Tsarenko, 2007) for the Ukraine in 2005 an average weighted electricity tariff for non-households accounted for UAH 0.198 per kWh, this is about 3€/100kWh.

Case study results: in €/100 kWh

Hungarian plants (CS1, .., CS4): 17.7, 8.7, 10.8, 5.1

Ukrainian plant: 6.3

Based on the oxygen demand for BOD_5-degradation, nitrification and denitrification, the removal efficiency (see chapter 3.2.3) and a share of 60% of the total energy consumption of the plant for aeration the following factors can be derived:

Table 9: 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

Excursus sludge digestion

In this section a brief overview on the investment costs of sludge digestion is given (data provided for Germany by (ATV 1995), (ATV 1996), (Nellenschulte 2003)). The costs comprise costs of construction, installations, gas tank and combined heating plant.

Annually about 20 kg dm/inh.d of sludge is produced amounting to 0.5m³ sludge (4 % dry matter) per year respectively 1.35 kg /inh.d

The gas production per inhabitant is about 18 l/day. The CH_4-content (calorific value 10 kWh/Nm³) of the gas produced can be assumed with 65% amounting to a total energy content of 42.7 kWh/inh.y.

Typically combined heating plants can convert 30% of the gas produced into electricity and 60% into heat. Assuming an electricity price of ca. 8€/100 kWh the energy costs substituted by the combined heating plant are roughly 3€/inh.y.

The investment costs decrease with increasing size of the plant: plant with 50000 pe: 30€, 100000 pe 24€, 150000 pe: 20€. Compared to the total investment costs of a CNDP-plant theses costs are about 10%.

It can be concluded that the sludge digestion is economically of interest for plants larger 40000 pe.

3.2.2.3 Maintenance

Maintenance is related to the physical size of the plant and the number of tanks and pieces of machinery it is composed of.

To evaluate the costs of maintenance a ratio of maintenance costs to the total annual costs of wwtps are used.

According (ATV, 1995) maintenance costs amount to 3.5% of the annual costs (min. 1%, max. 8%). These costs are mainly influenced by the level of technology and the age of the plant (low costs in the first years).

(Schönenberg, 1988) indicates a percentage of 12 % of the operating costs which would be 6% of the annual costs (assuming that 50% of the annual costs are due to the operating costs).

In this project maintenance is included in the other cost-categories.

3.2.2.4 Chemicals

Chemicals used in the plants are mainly related to P-precipitation and to sludge dewatering.

The amount of P to be removed to meet the effluent standards is decisive for the costs of precipitants. The P-load to the treatment plant is primarily caused by human metabolism (faeces, urine), the use of P-based detergents and contributions from industry. However, diffuse contributions from urban drainage, as well inputs from mechanical waste disposal systems (built into the outlets of kitchen sinks) may also make a contribution. Where separate sewer systems are used, miss-connections between the two systems and of wastewater from washing machine wastewater outlets to the foul sewer system, may by-pass waste water treatment works. In the project the compulsory introduction of P-free or reduced-P detergents will be considered.

As P-precipitants Fe- and Al-salts will be considered. For these two products transport costs can be neglected. If lime would be used, transport costs would become significant.

The precipitation process is decisive for the necessary construction cost for P-precipitation. The construction costs for P-precipitation as pre-precipitation (precipitant is added in the influent of the primary settling) and/or as simultaneous precipitation (precipitant is added e.g. in the biological treatment tank or to the activated sludge circle) are negligible. According (Lindtner, 2007a) the investment costs for P-precipitation in Austria range from 5,000 – 10,000 € (plants 1,000 – 5,000 pe) up to 20,000 – 25,000 € (plants > 50,000 pe) under the assumption that no separate housing for the tanks and the dosing system is needed. Considerable costs arise in the case a separate precipitation tank (post precipitation treatment) is constructed which would increase the construction costs by 15 to 20% (compared to a mechanical- biological treatment plant). However post precipitation is only used if extremely low P-concentrations have to be achieved. (lakes).

The P-concentration in the raw municipal waste water is relevant for those treatment plants which have to apply P-removal to comply with the P-emission standard.

The following assumptions were made:

Emissions from population:

- The specific P-emission per inhabitant excluding detergents is 1.7 gP/inh.d
- Automatic dish washer detergents are P-based. In the last 15 years a considerable increase in the use of P-containing detergents in automatic dishwasher products was observed in Germany In the beginning of the 1990ies the P-emission in Western Germany stemming from detergents use in households dropped to 2000 tP. Mainly due to the increase of the use of automatic dishwasher products the P-emissions increased again amounting to 3000t in 1996 and 5100 tP in 1999 (UBA 2007). Including the total German population this would mean a specific P-emission of 0.2 gP/inh.d. It can be assumed that the consumption of automatic dish washer products in the eastern parts of Germany was considerably lower at that time and the specific emission from persons in the western parts is higher. The number of dish washers has increased between 1993 and 2003 in Germany by about 100% (considering only the ”old” German countries by 65%) (UBA 2007a). In 2005 about 60% of German households possessed a dish washer (Destatis 2007a) still bearing a potential for an increase. In our calculations a consumption of 0.3 g P/inh.d is assumed. For eastern European countries this value will be lower. It is currently not possible to replace sodium tripolyphosphate (STPP) in automatic dish washer products. The “zero-laundry detergent scenario” depicted below includes the specific loads stemming from faeces and automatic dishwasher detergents.

- The amount of P-based laundry detergents consumed per inhabitant differ in a broad range. In Western countries like Austria, Germany or or Switzerland, the maximum consumption of P-containing laundry detergents in the 1980s amounted to 3 g P/inh.d. It has to be recognized that the composition of detergents has changed in the last decades. For instance the total amount of STPP contained in washing powders has been reduced from 50% to about 25% (or even less). Therefore "modern" P-containing laundry washing powders use less STPP per washing cycle. Depending on the hardness of the washing water 4 to 13 kg (Fox et al. 2002) of washing powders are consumed per inhabitant. Assuming a consumption of 4 – 13 kg washing powder with an STPP concentration of 25% per inhabitant would mean a specific P-emission of 0.7 – 2.2 gP/inh.d. In 7 countries of the EU 25 only phosphate free laundry detergents are used (EU Commission 2007). The term "phosphate free" indicates compliance with national legislation limiting phosphate content (not necessarily zero). The specific consumption of P-based detergents differs in a broad range – from 0 gP/inh.d up to 0.84 gP/inh.d in Hungary (and an outlier of 2.8 gP/inh.d in Slovak Republic) (INIA, 2006). It has to be recognised, that in several countries (i) P-free and P-based detergents are available on the market, (ii) that the current consumption can change and (iii) that several countries in the catchment of the Black Sea currently consume (much) less detergents than before the economic breakdown. This means current consumption patterns can not be seen as representative for the future consumption. Therefore in an example below the consumption of P-based detergents covers the range 0 to 1.5 g P/inh.d.

Emissions from Industry treated in municipal wwtps

- The organic pollution from industry and trade expressed as population equivalents (pe_{ind}) was assumed as follows: agglomerations > 100000 pe: 1.2 pe_{ind}/inhabitant.day, 2000-100000 pe: 1 pe_{ind} /inh.d, <2000 pe: 0.2 pe_{ind} /inh.d; These assumptions are based on recent studies in Austria reflecting well developed economic activities. In respect to the economic transition process with lower economic intensity in the CEE countries the following reduction for the amount of pe_{ind} per inhabitant.d have been applied for the calculations: CZ, HU: minus 25%, all others: minus 50%
- P-Emissions from industry: 1.1 gP/pe_{ind}.d (Zessner & Lindtner, 2003)

General assumptions

- The water consumption of 1 pe: 200 l
- Beta-value: 1.8 (Beta value: molar ratio of precipitant (Fe, Al) : P)
- The amount of sewer infiltration water influences the P-concentration in the raw waste water and as a consequence the efforts required to meet the effluent quality standards differ; calculations were carried out with 100 l sewer infiltration water per pe.

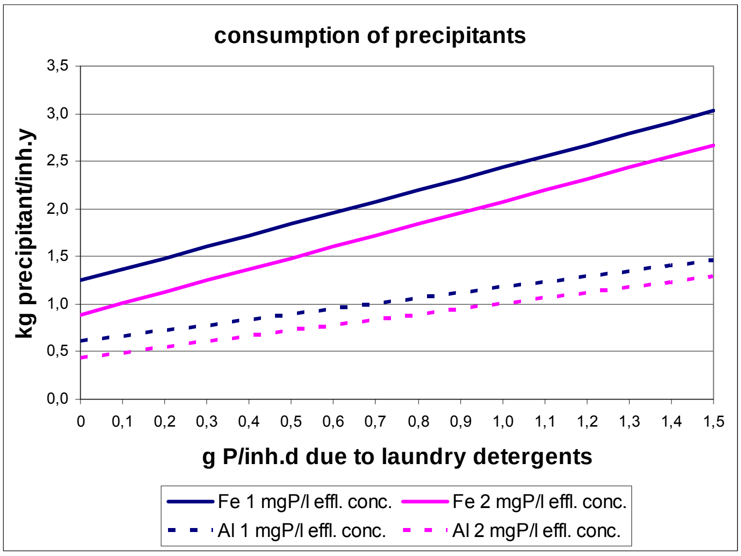

Figure 6: consumption of Fe- and Al-precipitants depending on the consumption of P-based detergents (Beta = 1.8)

The demand for Fe-salts is about double that of Al-salts.

The water consumption per pe and the sewer infiltration rate impact the amount of P to be precipitated and the total load emitted by wwtps. Sewer infiltration rates in the same order of the water consumption per pe double the effluent load. Higher amounts of sewer infiltration loads lower the amount of P which has to be removed and consequently lowers the consumption and costs of precipitants. On the other side high sewer infiltration rates increase the costs e.g. of pumping and often lowers the temperature of the waste water. The temperature of the waste water influences the removal capacity for Nitrogen. High amounts of sewer infiltration water and low temperature of the waste water result in larger volume requirements for aeration tanks.

In the figures below a specific P-emission of 1.65 gP/inh.d (caused by faeces only) is assumed. At sewer infiltration of 150% dry weather flow (200 l/pe.d) no P would have to be removed from the waste water meeting an emission standard of 2 mgP/l. Under such condition the goal of the emission standards cannot be achieved at all

In practice the sewer infiltration rate should be lower.

The use of P-based detergents increases the amount of P to be removed.

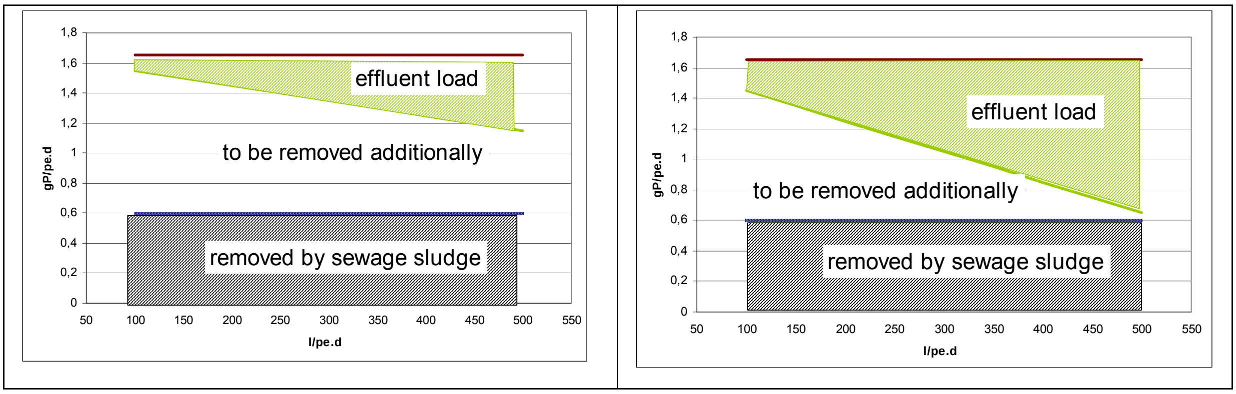

Figure 7: impact of raw waste water amount on the effluent load: effluent conc.: left 1 mgP/l, right: 2 mgP/l

If standards for P-concentrations of 1 or 2 mgP/l in the effluent exist, P-precipitation (or enhanced biological P-removal) is necessary even if no P-based detergents are consumed (except the sewer infiltration rate is very high as depicted above). Reasonable restrictions of sewer infiltration is a prerequisite of cost efficient water protection, especially for nutrient control.

Costs are assessed as follows:

1. Calculation of the amount of P to be removed via precipitation to meet the emission standards
2. Calculation of the amount of precipitants needed (Beta 1.8)
3. Evaluation of the costs of precipitants (Fe and Al-salts)

The amount of P to be removed will be calculated as follows

1. Removal of 0.6 gP/pe due to sludge production from C-removal
2. Total load minus P-load removed by biological treatment minus P-load in the effluent according the emission standards = P-load to be precipitated

For cost calculations the following prices for P-precipitants were used:

Fe-salts: 0.9€/kg active ingredient

Al-salts: 2.35€/ kg active ingredient

The emission of 1 g P/inh.d stemming from laundry detergents causes additional costs for P-precipitation. These costs are 1.1 €/pe.y (Fe-salts) – 1.35 €/pe.y (Al-salts) (Beta 1.8).

Chemicals used for sludge dewatering

Chemicals (polymers, $FeCl_3$ and lime) have to be applied for dewatering the sludge.

Depending on the type of dewatering system (chamber filter press, belt-type filter, centrifuge) different amounts of chemicals are applied. In Kroiss et al. (2001) the mean values for costs for dewatering sludge range between 27 and 36 €/t dewatered sludge (resp. 90 – 120 €/t dry matter). The share of chemicals amount to 16 – 48 €/t dm (almost 20% up to 45% of the total costs of dewatering) (further details see chapter 3.2.2.5)

3.2.2.5 Sludge treatment and disposal

Sewage sludge is a main product of the waste water treatment process. 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 Zeolite-based detergents also increases the amount of sludge produced.

The daily specific sludge production varies between 40 to 60 g dm/pe.d (15 – 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 amount of additional sludge produced in plants where P-removal is required is based on the following assumptions:

- Calculation of the P-amount to be precipitated (see chapter on chemicals)
- Calculation of the specific amount of additional dm/kg P:
  - Precipitant per kg P: 1.8 kg Fe/kg P, 0.87 kg Al/kg P
  - Beta-value: 1.8 (Beta value: molar ratio of precipitant (Fe, Al) : P)
  - Sludge production: 2.5 kg dm/kg Fe (Beta = 1,5), 4 kg dm/kg Al (Beta = 1.5)

These assumptions lead to an additional dm production of 9.7 kg dm/kg P to be precipitated using Fe-salts, and 7.5 kg dm/kg P using Al-salts (Beta 1.8).

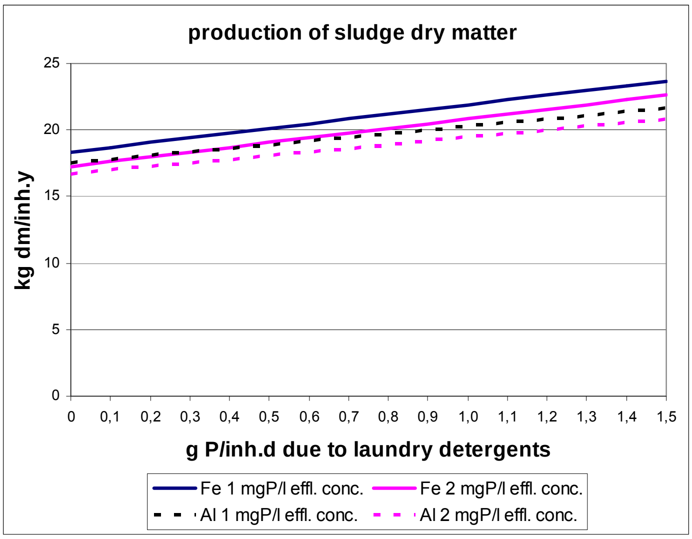

Figure 8: specific production of dry matter depending on the consumption of P-based detergents

The total amount of sludge dry matter produced using Fe-salts is 5 to 10% higher compared to the use of Al-salts.

The use of Zeolites instead of P-based detergents also increases the production of sewage sludge as almost the entire amount of zZeolites remain in the sludge. The Zeolite consumption in Germany amounted in 1999 to 4.5 g/inh.d (UBA, 2007). This amount can be considered as a maximum amount.

If standards for P-concentrations in the effluent exist, P-precipitation is necessary even if no P-based detergents are consumed.

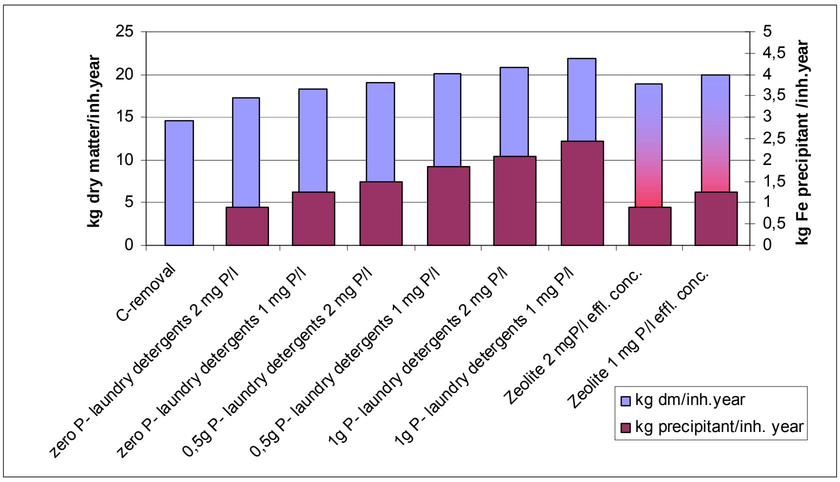

Figure 9: Sludge dry matter production and use of Fe-precipitants; Zeolite consumption 4,5g/inh.d

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).

Costs are assessed as follows:

1. Calculation of sludge production (see above)
2. Estimation of costs for dewatering
3. Evaluation of disposal options
4. Related costs for disposal

Costs of dewatering

Depending on the type of the dewatering device the costs in Austria vary from 91 to 121 €/t dm.

Table 10: costs for sludge dewatering in Austria (own calculations based on (Kroiss et al. 2001))

in €/ t dm	chemicals	personnel	ext. serv.	electricity	sum
chamber filter press	42	37	9	7	95
belt-type filter	16	46	13	16	91
centrifuge	48	45	14	14	121

For all countries under investigation the costs from chemicals were assumed to be equal (world market). For the other cost-categories local data (salaries, electricity prices) were considered. Mean values of the 3 dewatering types using local data are depicted in the following table.

Table 11: 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**

Compared to Austria sludge dewatering in the other countries under investigation is between 10% and 20 % cheaper.

As depicted above the additional production of dry matter due to P-precipitation amounts to 9.7 kg dm/kg P using Fe, and 7.5 kg dm/kg P using Al (Beta 1.8).

The emission of 1 g P/inh.d stemming from laundry detergents causes additional costs for sludge dewatering. These costs are below 0.36 €/inh.y.

The costs of dewatering increase only slightly with increasing use of P-based detergents. The costs for precipitants become more important the higher the amount of P-based detergents is.

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.

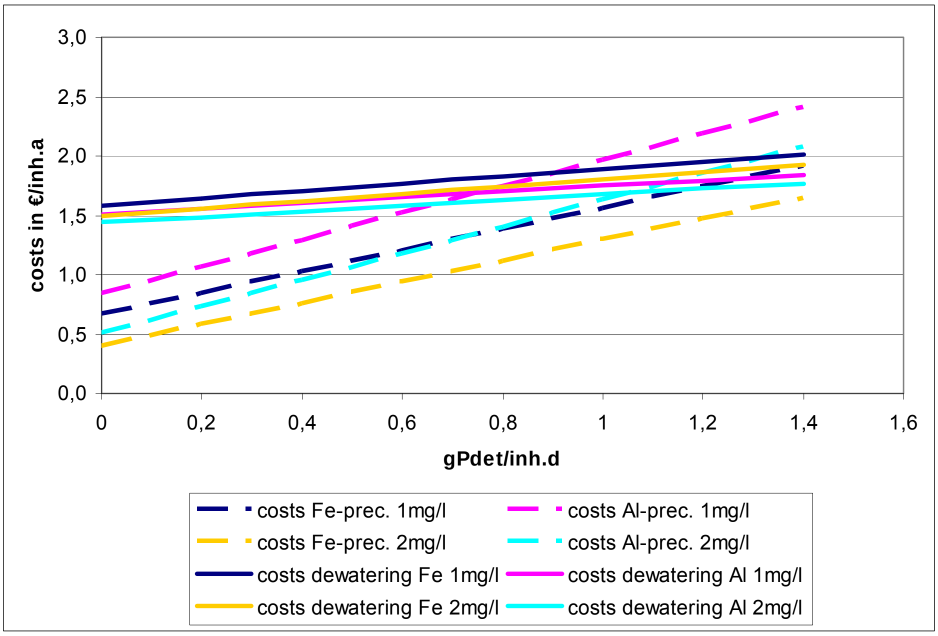

Figure 10: Costs related to P-based detergents for precipitants and sludge dewatering in Bulgaria (Fe 1 mg = iron salts are used as precipitants to apply to an emission standard of 1 mgP/l)

Comparison of carbon removal and CP-plants in respect to sludge dewatering (Austria)

C-removal only: 1.35 €/pe.y: 0.6 €/pe.y personnel costs, chemicals for dewatering: 0.5 €/pe.y, 0.25€/pe.y for electricity and external services.

CP-removal: 1.8 €/pe.y: 0.75 €/pe.y personnel costs, chemicals for dewatering: 0.65 €/pe.y, 0.4€/pe.y for electricity and external services. The additional costs related to the additional sludge production amount to 0.45€/pe.y.

Sludge disposal:

Several options are possible, depending on the national legislation: (agricultural) application on land with or without pre-treatment (e.g. composting), direct disposal in landfills, disposal after pre-treatment by incineration, dumping in the sea, etc. The direct disposal is not possible any more in several countries (e.g.) Germany or Austria as the content of organic carbon and/or the calorific heat value for materials to be disposed of is limited.

Landfill (with and without pre-treatment) can be considered as a temporary stock. However the P-resource stored in this stock can only be used if the sludge resp. the ash is stored in separate compartments of landfills or together with other wastes which have similar concentrations of P and heavy metals. The disposal of sewage sludge together with municipal solid waste or with ashes from waste incineration plants would spoil the potential P-resource.

Incineration in many cases is the most expensive option.

Agricultural application often is forbidden (in general or restricted to limited purposes) or has at least a negative image. Preconditions for the use of sewage sludge in agriculture are that the legal constraints (standards for maximum concentrations in the sludge, in the soils, regulations on the total heavy metal loads or dry matter to be applied; e.g. EU Directive 86/278) are fulfilled and that agricultural area is available and additional fertilizer application is needed (no competition with manure disposal!).

For Austria the costs of sludge incineration amount to approx. 170 €/t dm, for landfill disposal (which is not allowed anymore (only in exceptional cases) the costs amounted to about 85€/t dm. A typical price for use in agriculture is 65€/t dm (about 20€/t dewatered sludge resp. ca. 1.5 €/pe.y).

In most cases the disposal costs of sludge are related to the mass of material to be disposed of, this strongly depends on the moisture content or the material which can vary from almost zero (ash) to ≥ 75% (belt filter presses).

The prices of sludge disposal strongly depend on specific local conditions. From almost zero (in the case that the landfill and the treatment plant are owned by the municipality and no disposal charge is required (Tsagarakis, 2002) to > 100€/t dry matter (ÖWAV, 2007).

The data base on sludge management 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.

Several citations shall indicate the problems of the data:

- (DHV CR, 2001): Landfilling is the major disposal route for all categories of waste in CEE (Central and Eastern Europe) countries. By 1999, within the CEEC, there were only 7 large municipal incinerators (capacity over 3 tonnes/hour) in operation in the Czech Republic, Hungary, Poland and Slovak Republic and 3 smaller ones in Poland. However sewage sludge is incinerated in industrial plants like cement kilns. Landfill disposal costs in CEE countries are significantly cheaper than in Austria. No information is given on the costs of sludge disposal but on user charges of municipal wastes are depicted (including collection system, disposal, etc.) indicating for the Czech Republic 15-20€/ton (out of this approximate average costs of municipal waste disposal in landfills of ca 5 €/ton). For Bulgaria, Romania and Slovakia user charges of municipal wastes of less than 10€/t are indicated. Using the same ratio as for the Czech Republic the disposal costs would amount to less than 2.5 €/t. As the annual production of sewage sludge (20% dry matter) amounts to 60-80 kg /pe.y the disposal costs amount to less than 0.25 €/pe.y in BG, RO, SK.

- (MMDD, 2004) provides information on sludge management and related costs in Romania for the year 2003: Almost 60% of the total sludge produced is disposed of in landfills, 25% is stored at the plant, 10% is used in agriculture, about 5% is combusted or used for other purposes (like composting). The costs for incineration (assuming 80 kg sludge, 25% dry matter) amount to 0.3 – 1 €/pe.y, for disposal in landfills 0.1 – 1.6 €/pe.y and for agricultural use 0.6 – 3.2 €/pe.y. For many of the landfills it has to be assumed that they are not in convergence with the normative EC-requirements, or can become compliant soon.
- According UNEP (2000)) in the AC10 (Accession Countries) but most probably in all transition countries, the reuse of sewage sludge from treatment plants as fertilisers in agriculture is not common. In Romania the treated sludge is not recommended (or collected) as fertiliser for health and ethical reasons. Further official reasons were the high fertility rate of the Romanian soil and the lower costs and higher efficiency of chemicals used as fertilisers. According to (Rojanschi, 1999), (cited in (UNEP 2000)) in Romania nearly all sewage sludge is disposed on drying platforms. A small amount of sludge is also discharged into the Black Sea, mostly out of the bathing season. The equipment of the drying beds is quite often old, and maintenance is often not adequate. That leads to infiltration into the ground, contaminating the groundwater and soil. Filled drying beds were abandoned, without any further care, and new ones were created. Especially in the CIS, the disposal of untreated sludge is carried out on huge sludge fields. Sludge management is hampered by a lack of dehydration technologies. On sludge fields, the sludge is drying out naturally, which creates problems in the dry period of the year through dust and smell trouble for the surrounding population, as well as in the wet period of the year through washing out the sludge into water bodies and /or groundwater. Most sludge field capacities are exhausted, they are overloaded, and there is not much space to build new ones, except in Russia. Sludge fields are not always monitored, ground water and soil contamination are common (UNEP 2000).
- (EC 2001) provides data on the major outlets for sewage sludge in Accession countries: CZ: 70% agricultural use, 30% landfilling, HU: 100% agricultural use, SK 71% agriculture, 11% landfill, 18% others, SL: 20% agricultural use, 60% landfilling, 20% other

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 assume (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.

Landfill: only construction, no installations; share salaries: 55% of the costs; costs in Austria: 85 €/ton dry matter

Incineration: 40% construction costs, 60% installations (machinery, electric installations, cleaning devices), costs in Austria: 170 €/ton dry matter

Agriculture: 2/3 machinery, 1/3 personnel costs; costs in Austria: 65 €/ton dry matter

Composting: same assumptions as agriculture; costs in Austria: 80 €/ton dry matter

These assumptions resulted in the following sludge disposal costs per ton dry matter:

Table 12: 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

3.2.2.6 Levies of discharge

Could not be obtained.

3.2.2.7 Other costs

Other costs (including costs for administration, laboratory, etc.) will be estimated as the percentage of the total operation costs excluding the sludge disposal costs of the Austrian plants.

The share of other costs depends on the size of the plant. For plants below 50000 pe other costs amount to 13%, for plants above 100000 pe to 6% of the operation costs (excluding sludge disposal).

3.2.3 Nutrient removal efficiency

The removal efficiency of treatment plants is defined as the difference of the load in the inflow and of the load of a substance in the outflow divided by the total inflow load.

In our investigations only conventional activated sludge reactors are considered, as these systems are very common, and a lot of data is available (at least for “western” countries). However the methodological approach depicted above can also be applied to other treatment processes.

A part of the nutrients in the inflow is removed as primary sludge (if there is a primary settling tank) another part is incorporated in to the biomass of the bacteria and removed as excess sludge (secondary sludge).

For N and for P the removal via the sludge is between 20% and 40% of the inflow load.

For an additional N-removal a nitrification / denitrification step is needed. Usually 70% (maximum 90%) removal can be achieved. The removal is limited by the availability of carbon sources and the temperature of the waste water (in winter time).

Additional P-removal can be increased simply by adding precipitants. Enhanced biological P-removal can lower the demand for precipitants. Total removal efficiency of 80 to 85% for P can easily be reached. However effluent concentrations ≥ 0.5 gP/l would require higher loads of precipitants.

For the calculations of the cost effectiveness the N- and P-amount additionally to the N and P removed via the sludge of biological treatment will be used. (N/P removed via sludge of biological treatment + additionally removed N/P = N/P removed total).

Assumptions on the nutrient removal related to the inflow load:

C-plants: 20% N and 40% P in the sludge

CN plants: 20% of N and 40% of P remains in the sludge, further 20% of N is denitrified.

CND plants: 20% of N and 40% of P remains in the sludge, further 55 % of N is denitrified.

CNDP plants: 20% of N and 85% of P remains in the sludge, further 55 % of N is denitrified.

Table 13: removal rates for N and P of different treatment types

in% of inflow	C-plant	CN plant	CND	CNDP
N	20	40	75	75
P	40	40	40	85

3.3 Results

3.3.1 Investment costs/annual capital costs

Investment costs in Austria for A CNDP plant with 100000 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 for plants (150000 pe) amount to 13 (A), 11 (CZ) and 9.5 (UA) €/pe.y (5% real interest rate, 30 years depreciation).

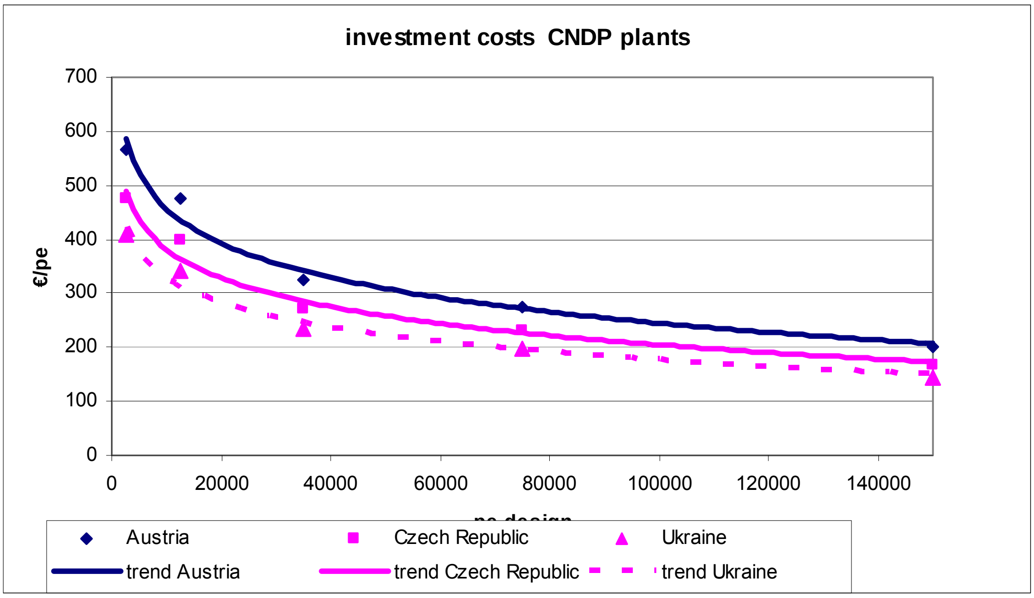

Figure 11: investment costs for CND/CNDP plants in A, CZ and UA in €/pe design load

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

Details on capital cost in €/pe.y for different plant configurations and different design capacities are presented in the Annex.

3.3.2 Comparison with the DABLAS investigations

In the DABLAS II project (ICPDR 2004) 191 municipal sector investment projects (representing a population equivalent of more than 27 million) were assessed. Among the 191 projects, 66 were fully financed.

The plants comprise different design capacities, it is indicated if N or P-removal is applied or not and the investment costs are given.

This data base was evaluated in the view of this project. For our investigation we used only new plants between 3000 and 250,000 pe and separated these plants into the categories “only Carbon removal” (10 plants), “Carbon and Nitrogen Removal (7 plants) and Carbon, Nitrogen and Phosphorus Removal” (29 plants)”. A first evaluation showed that the costs for C+N-removal plants would be higher as the costs for C+N+P-removal plants. As the number of C+N removal plant was small and the additional costs for P removal are very low these two plant categories were merged together.

Out of the 10 C-removal plants investigated 4 are located in HR, 2 in BA, and 1 in BG, SL, CS and UA. Out of 7 new CND-plants 2 are in BA and HR, 1 in SK, BG and MD. From the 29 new plants with C-, N- and P-removal 22 are in BG, 6 in SL and 1 in HR. investigated. This means: 39 plants out of the 46 are in economically "less developed" countries.

As a further step the plants were categorised into the following classes: 3000 – 20000 pe, 20000 – 50000 pe, 50000 – 100000 pe. The following diagram depicts the average values for the 4 classes, the category with C+N and C+N+P removal in comparison with the corresponding Austrian values (details from the DABLAS data are shown in the Annex).

The evaluation clearly shows the economy of scale.

The Austrian investment costs are 25 to 30% higher as those for the new plants with nutrient removal depicted in the DABLAS report. This is fully in line with the costs estimated in the course of this project depicted in chapter 3.3.1.

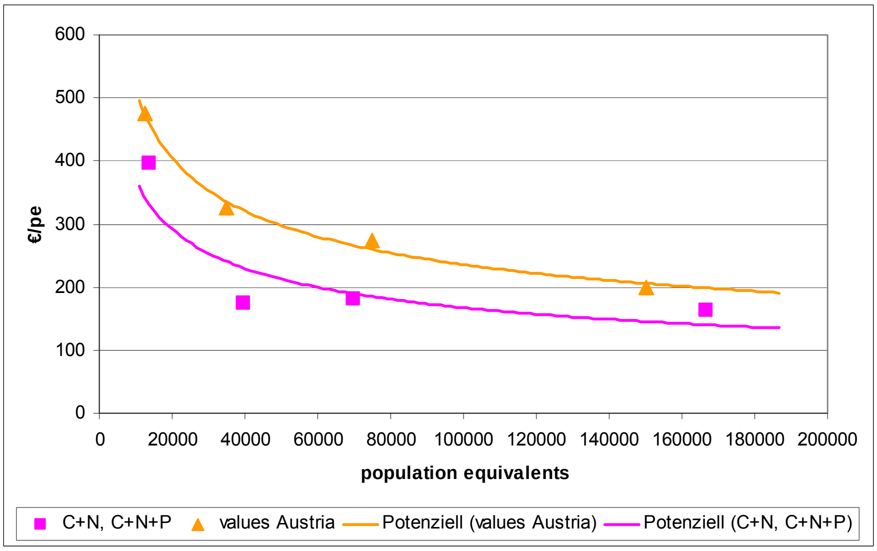

Figure 12: Investment costs for CND- and CNDP-plants in Danubian countries based on the Dablas report and CNDP-plants in Austria

3.3.3 Operation costs

It is important to bring to mind that for the operation costs the following assumptions on personnel costs were made: (i) the labour productivity in all countries under investigation will be the same in 30 years, and (ii) the difference in the salaries in the western and the CEE countries now will be reduced by 50% within 30 years.

Compared to Austria 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.

Details are presented in the Annex.

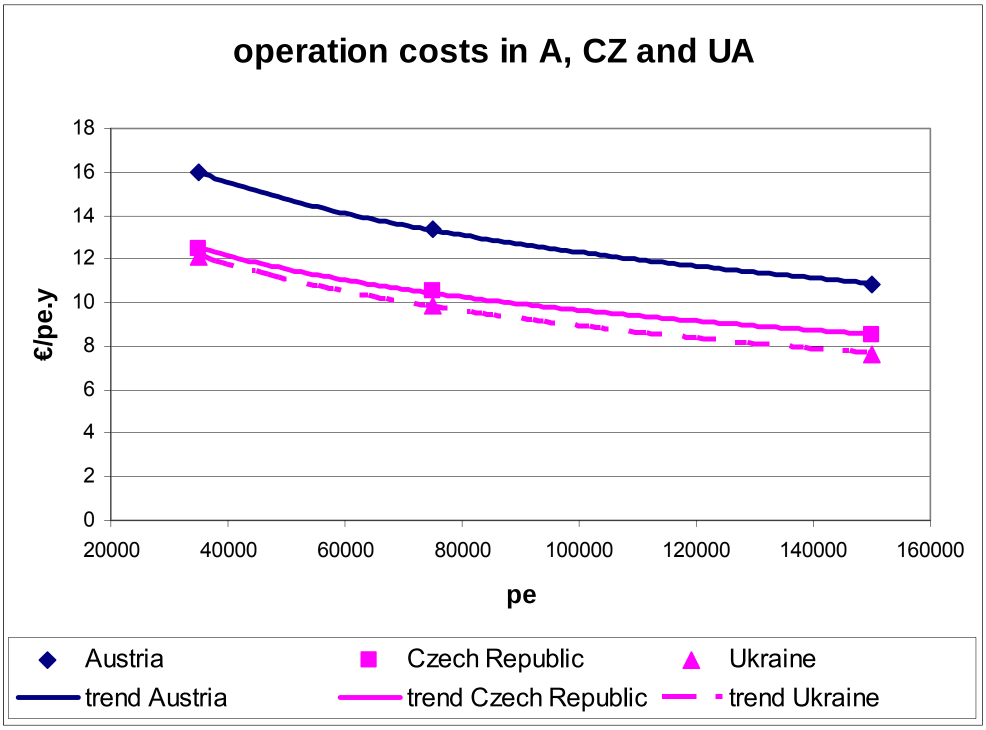

Figure 13: operation costs for CND/CNDP plants in A, CZ and UA in €/pe.y

The major cost category of operation costs in Austria and Germany 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) – 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. In small plants the costs for chemicals are higher than the costs for sludge disposal, for large plants these two shares are almost equal (under the assumptions made for sludge disposal in these calculations, which in fact do not reflect the current situation).

Table 14: median operation costs of CNDP plants and share of cost categories

operation costs CNDP (medians)

	A	BG	CZ	HU	RO	SK	SI	TK	UA
costs €/pe, <50000 pe	**16,0**	**11,8**	**12,5**	**11,3**	**12,5**	**11,9**	**11,8**	**13,1**	**12,1**
materials/chemicals in %	12	17	16	17	16	16	17	15	16
personnel costs in %	39	43	36	32	37	31	35	37	48
external costs in %	9	8	9	9	8	8	9	7	8
energy costs in %	13	11	17	20	18	21	17	20	7
sludge disposal in %	17	12	13	13	11	13	12	11	11
other costs in %	9	10	10	10	10	10	10	10	10
costs €/pe.y, >100000 pe	**10,9**	**7,7**	**8,5**	**7,9**	**8,5**	**8,4**	**8,0**	**8,9**	**7,6**
materials/chemicals in %	13	18	17	18	17	17	18	16	19
personnel costs in %	30	34	28	24	29	23	27	28	40
external costs in %	9	9	9	9	8	8	9	8	8
energy costs in %	18	15	23	26	25	28	24	27	10
sludge disposal in %	25	19	19	18	17	18	18	16	18
other costs in %	5	5	5	5	5	5	5	5	5

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 as about 20% lower as compared to CNDP plants.

3.3.4 Annual costs

For the calculation of the 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.

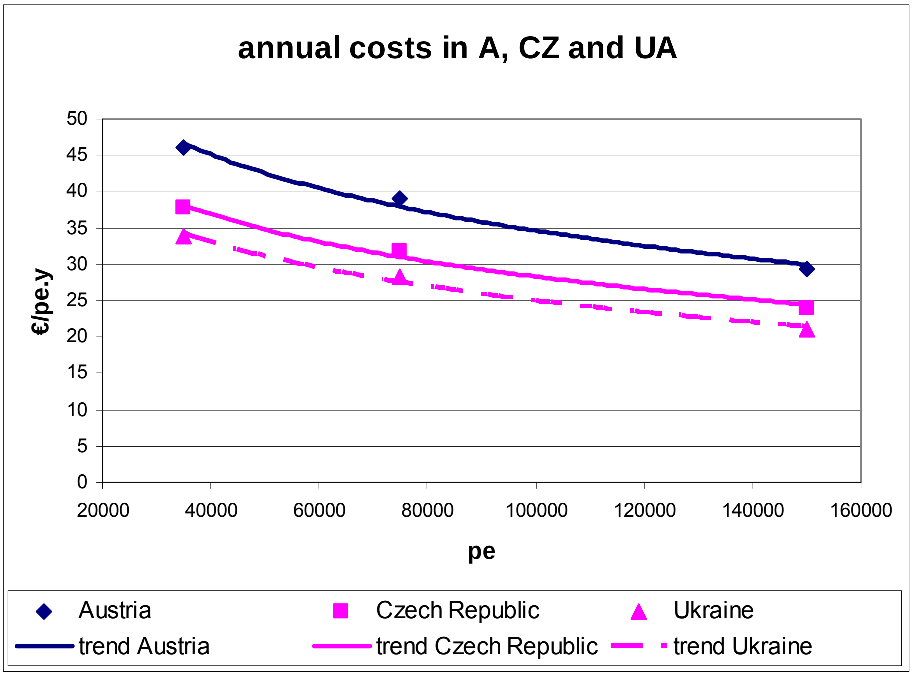

Figure 14: Annual costs for CND/CNDP plants in A, CZ and UA in €/pe.y

Annual costs of plants with Nitrification but without denitrification are 4 - 5% lower compared to CNDP plants.

There is no significant difference in the annual costs of CN and CND-plants.

Annual costs of plants with C-removal only are ~ 12% lower.

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.

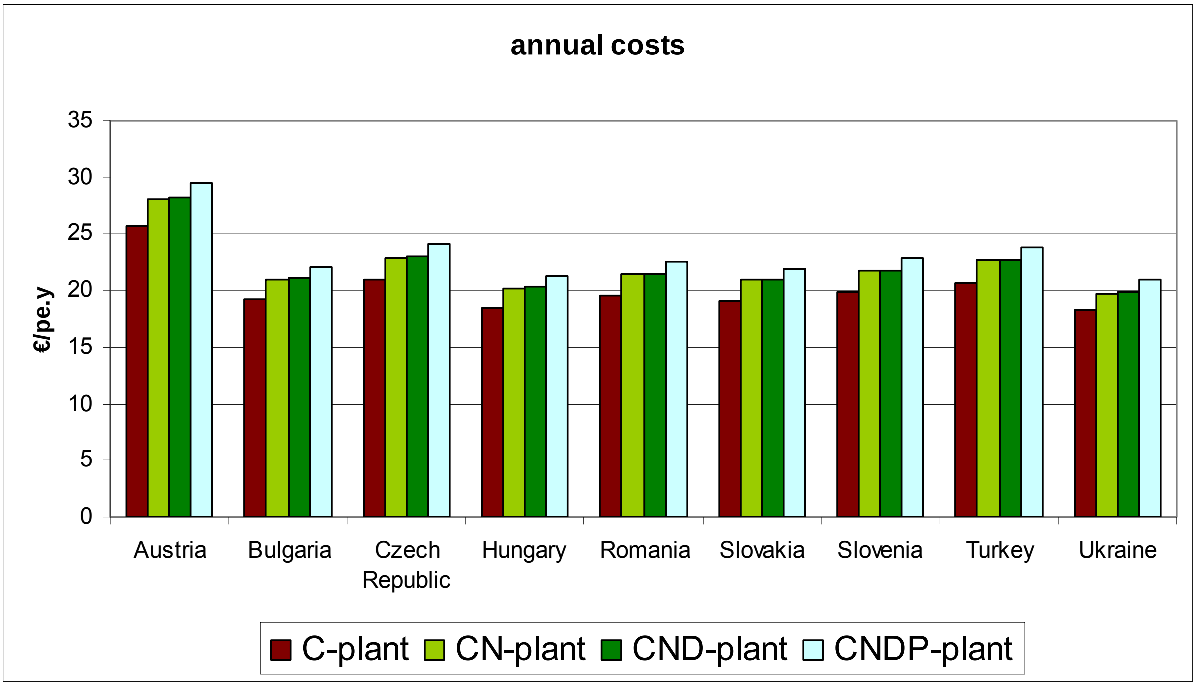

Figure 15: annual costs of wwtps > 100000 pe design

Sensitivity analysis

Investment costs amount at least to 60% of the total annual costs. The sensitivity analysis therefore concentrates on variables used for the calculation of investment costs. Partly these variables also impact operation costs.

The sensitivity of the following variables were investigated:

- Real interest rate
- Depreciation period of the plants
- Labour productivity

Real interest rate

The interest rate heavily influences the costs:

An increase of 1% of the interest rate increases the total annual costs by 7,5% (6,8% by an increase of the interest rate from 3% to 4%; 8,2% by an increase from 7% to 8%).

The following figure shows the respective changes in the total annual costs for CNDP-plants (mean of all countries and all sizes; differences between countries and between sizes deviate in the maximum by 5% from the mean depicted).

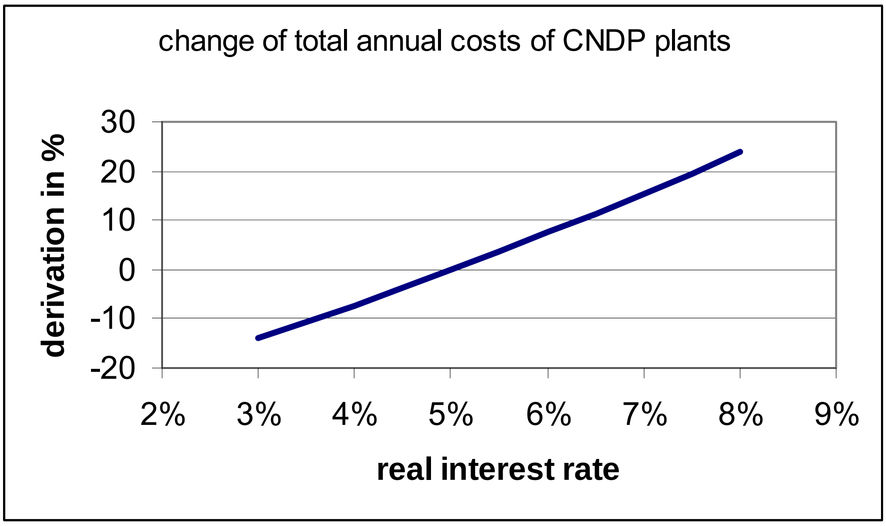

Figure 16: Impact of interest rate on annual costs (mean)

Depreciation period of the plant:

Calculations in this project are based on the assumption of a depreciation period of 30 years. A variation of the depreciation between 25 an 40 years showed the following results:

A depreciation time of 25 years increases the costs in the countries by 6%.

A depreciation time of 35 years lowers the costs in the countries by 4%.

A depreciation time of 40 years lowers the costs in the countries by 7%.

The following figure shows the respective changes in the total annual costs for CNDP-plants (mean of all countries and all sizes; differences between countries and between sizes deviate in the maximum by 5% from the mean depicted).

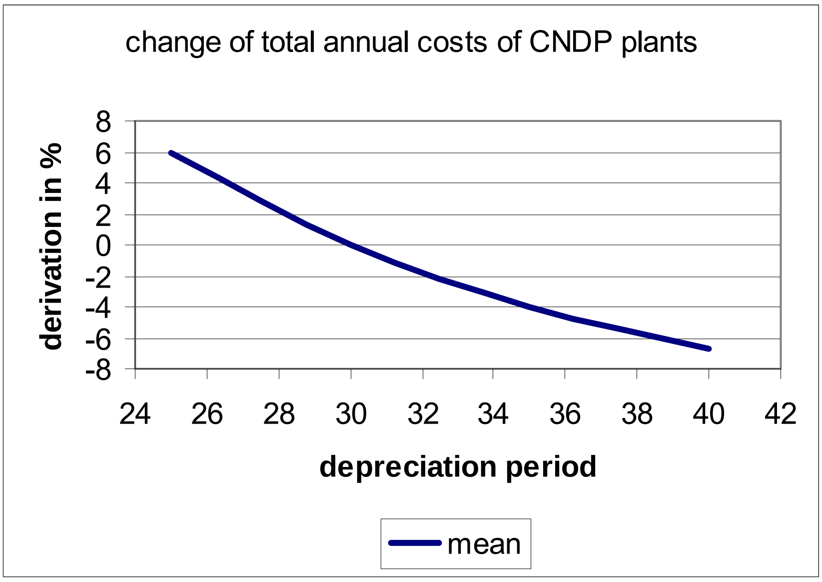

Figure 17: impact of depreciation period on annual costs (mean)

Labour productivity

The impact of labour productivity differs strongly between countries: assuming the same labour productivity in the countries as in Austria showed the following impact on the costs:

BG, RO, TK: UA: decrease of total annual costs by 20% - 26% for small plants and 18% – 23% for large plants.

Other countries: 8% to 13.5% decrease of annual costs

These reductions are highly hypothetic as an increasing labour productivity will lead to higher wages/salaries respectively higher wages lead to higher labour productivity.

Lowering the interest rate from 5% to 3% and assuming the same labour productivity in all countries as in Austria showed the following impact on the costs:

BG, RO, TK: UA: decrease of total annual costs by 30% - 37%

Other countries: 20% to 26% decrease of annual costs.

3.3.5 Cost effectveness

Cost effectiveness in waste water treatment is assessed as ratio of costs of the additional treatment process (nitrification/denitrification; P-precipitation) versus the obtained additional emission reduction.

For the interpretation of the effectivenesses given it should be noted, that the main function of wwtp is Carbon removal, independently if it is a C, a CN, a CND or a CNDP plant.

The additional purpose

- of CN plants is to reduce Ammonia emissions substantially,
- of CND plants is to remove N
- of CNDP plants is to remove N and P
- of CP plants is to remove P.

It makes sense to relate “effectiveness” in respect to one specific purpose of treatment (e.g. N-removal) only to the costs occurred to fulfil this additional purpose.

In the following sections the mean values of the three different sizes of plants as well as selected graphical presentations are presented. Details can be found in the Annex.

3.3.5.1 Cost effectiveness of measures removing N

The highest cost effectiveness provides the installation of CND plants instead of a CN plants. The mean annual costs are less than 0.4€/kg N additionally removed (less than 0.55€ for plants <50000 pe, for plants > 100000 below 0.2 €/kg N).

The cost effectiveness for N-removal if a CND plants instead of a C-plant is considered on average is less than 1.5 €/kg N additionally removed.

If costs of the whole treatment plant (C, CN or CND) are related to N-removal the resulting values are much higher. In this case N-removal is only a positive side-effect of Carbon (COD) removal. Nevertheless it can be seen that the installation of an additional CND step provides a high cost effectiveness.

Table 15: Mean values of cost effectiveness of the three plant sizes for different plant installations in €/kg N additionally removed

€/kg N (mean)	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
no-plant -> C-plant	41,8	31,7	34,1	29,9	31,8	30,8	32,3	33,6	30,2
no plant -> CN-plant	22,7	17,2	18,6	16,3	17,3	16,8	17,6	18,3	16,3
no plant -> CND-plant	12,3	9,3	10,0	8,8	9,3	9,0	9,5	9,9	8,8
C-plant -> CND-plant	1,5	1,1	1,3	1,1	1,2	1,2	1,2	1,3	1,1
CN-plant -> CND-plant	0,36	0,27	0,24	0,18	0,19	0,18	0,21	0,19	0,28

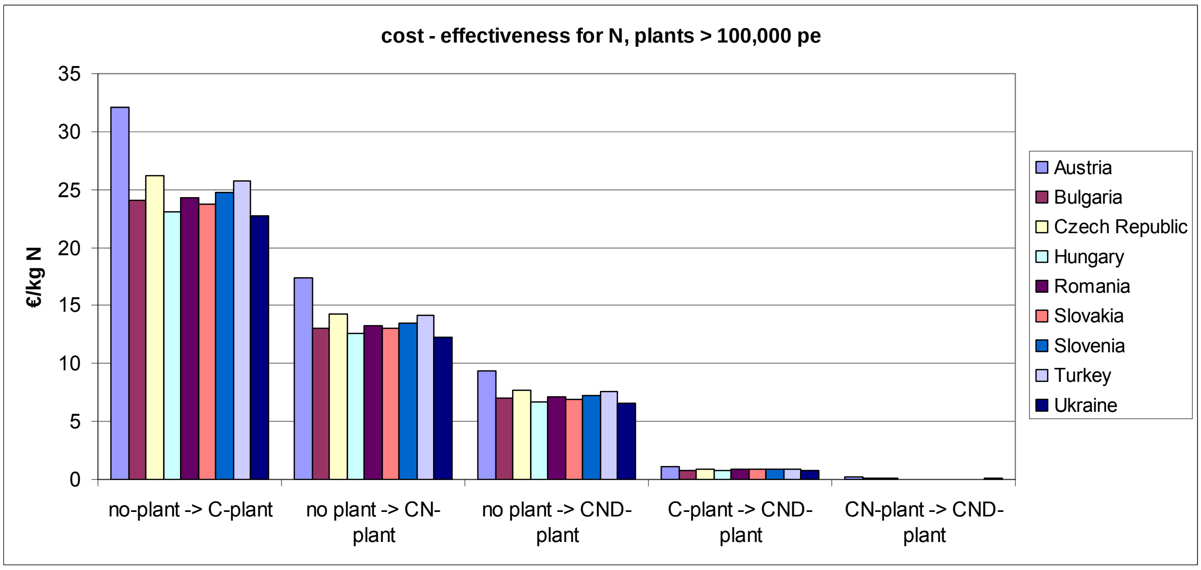

Figure 18: Cost effectiveness of N for plants > 100,000 pe for different plant installations in €/kg N additionally removed

The cost effectiveness depends on the size of the treatment plant, which will be illustrated by the upgrade of C -> CN and CN -> CND-plants for Austria and Romania.

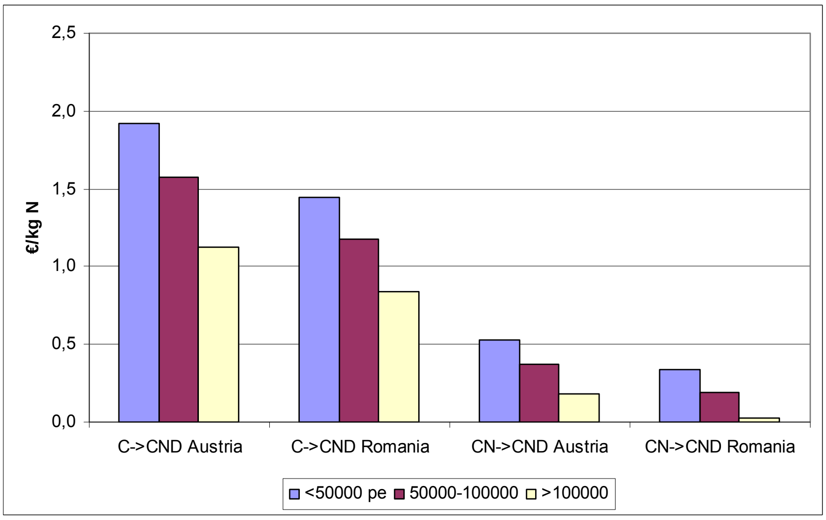

Figure 19: Dependency of cost effectiveness for N on the size of the plant

3.3.5.2 Cost effectiveness of measures removing P

Cost effectiveness calculations in respect to P have to consider the installation of P-precipitation at an existing C-, CN- or CND-plant. The costs for removing 1 kg P in addition are below 4.3 €/kg (Beta value of 1.8). As the main costs of this measure are related to chemicals (for precipitation and sludge dewatering), the difference between the countries is very small; the higher Austrian value is due to significant higher sludge disposal costs. If costs of the whole treatment would be related to P-removal the resulting values are much higher. It has to be taken into account that in this case P-removal is only a positive side-effect of COD removal. Anyway the most cost effective use of the costs in respect to P is achieved if additional P-removal is performed.

Table 16: Mean values of cost effectiveness of the three plant sizes for different plant installations in €/kg P additionally removed

€/kg P (mean)	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
no plant -> C-plant	118	89	96	84	90	87	91	95	85
no plant -> CNDP-plant	63	48	52	45	48	47	49	51	46
C-plant -> CNDP-plant	14,3	11,1	11,9	10,8	11,4	11,1	11,4	11,9	10,7
C-plant -> CP-plant	4,3	3,7	3,8	3,6	3,7	3,7	3,7	3,8	3,7

The cost effectiveness of additional P-removal does not depend on the size of the plant as the differing investment costs are negligible.

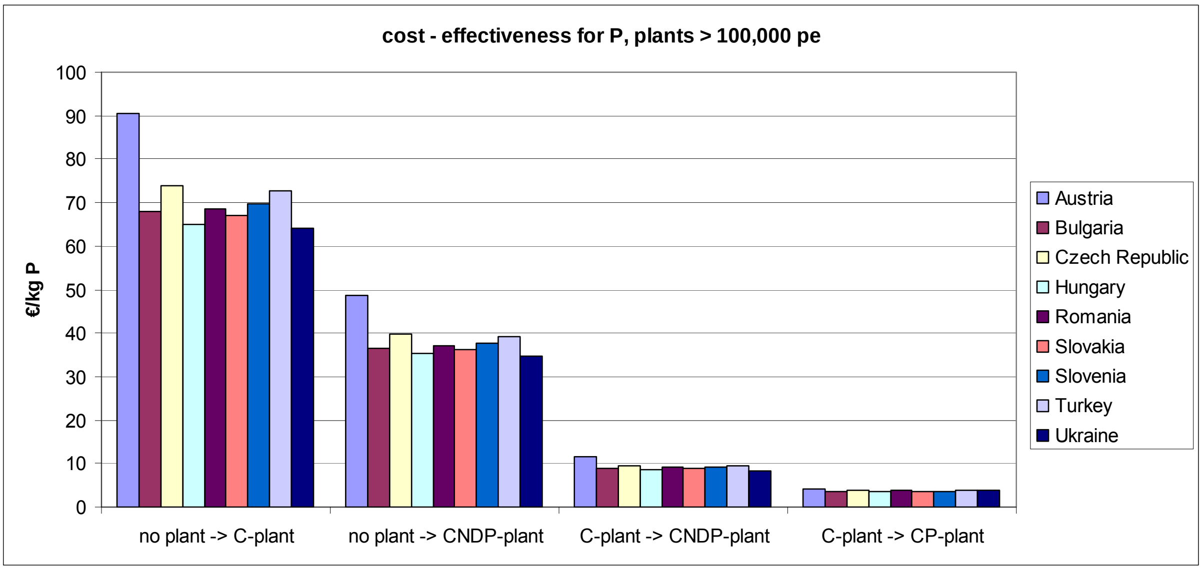

Figure 20: Cost effectiveness of P for plants > 100,000 pe for different plant installations in €/kg P additionally removed

3.3.6 Advanced treatment

In this section in brief the following treatment options will be introduced:

- Advanced N-removal: increase from 70% to 90% N-removal (additional N-removal of 0.8 kg N/pe.y)
  - Enlarging the aeration tank by 25%
  - Sand filtration + External carbon source methanol
- Advanced P-removal by flocculation filtration

A degree of utilisation of the plant of 70% is assumed for the calculation of the cost effectiveness.

Costs will be depicted only for the Austrian situation. All data presented, except some own calculations, is based on (Lindtner 2007) respectively literature cited there.

3.3.6.1 Advanced N-removal by enlarging the aeration tank

An enlargement of the volume of the aeration tank by 25% allows an increase of N-removal from 70% to 90%. Prerequisite is the availability of carbon for denitrification. 90% will only be achieved in plants without primary settling with simultaneous aerobic sludge stabilisation (plants above 40,000 – 50000 pe usually are equipped with an anaerobic sludge stabilisation). The costs for construction of the aeration tank increase by 25%, the costs for machinery and electrical installation remain on the level before.

The operation costs do not change: the additional energy for aeration is compensated by the higher denitrification potential and the reduced amount of sludge produced.

Specific costs for an upgrade of an existing aeration tank can be assumed to be 50% higher.

The total investment (construction) costs for the enlargement based on own calculations amount to 16 €/pe (100000 pe) and 19 €/pe (50000 pe) or annual capital costs of 1.0 and 1.2 €/pe.y respectively (30 years depreciation time, 5% interest rate). The cost effectiveness of this measure is 1.25 to 1.5€/kgN.

3.3.6.2 Advanced N-removal with external carbon source

At treatment plants with primary sedimentation usually not sufficient carbon is available to increase N removal from 70 to 90% consequently an external carbon source is required. In this case the form of a sandfilter with methanol dosage is depicted.

The following costs have to be considered:

- Investment costs for the sandfilter: 37 – 94 €/pe.y investment costs, 2.95 to 7.6 €/pe.y annual capital costs (20 years depreciation time as mainly machinery costs occur, 5% interest rate).
- Operation costs
    - Costs of methanol: 440 €/t in 2005; typically 3 – 4.5 kg Methanol are added per kg Nitrogen to be removed.
    - Energy costs: 2 – 5 kWh/pe.y
    - Additional production of sewage sludge: 1 kg dry matter per kg N removed

  Operation costs per year: 1.2 – 2.7 €/pe.y

The costs for the additional N-removal amount to 5.2 – 12.9 €/kg N removed.

3.3.6.3 Advanced P-removal by flocculation filtration

This procedure is a combination of precipitation, flocculation and sand filtration. This combination guarantees P-concentrations in the effluent of less than 0.2 mgP/l (under the condition that the precipitable P is less than 0.1 mg/l). Several costs are the same as for the advanced N-removal with external carbon sources.

It is assumed that this measure is taken to reduce P-concentration from 1 mgP/l to 0.2 mgP/l equalling to 50 gP/pe.y.

- Investment costs for sand filtration: 37 – 94 €/pe.y investment costs resp. 2.95 to 7.6 €/pe.y.
- Operation costs
    - Costs for precipitants: Fe-salts: 0.9€/kg active ingredient, Al-salts: 2.35€/ kg active ingredient; ca. 0.15€/pe.y (Beta 1.5)
    - Energy costs: 2 – 5 kWh/pe.y
    - Additional production of sewage sludge: 6.25 (Al) – 8.1 (Fe) kg dry matter per kg P removed (Beta 1.5)

  Operation costs per year: 0.75 – 2.2 €/pe.y

Total costs: 3.7 - 9.8 €/pe.y)

Cost effectiveness: 65 – 167 €/kg P removed additionally

Sewer system

Waste water management includes in addition to the treatment of waste water in treatment plants the related sewer systems. However the costs of the sewer system are beyond the scope of this project. Nevertheless some rough estimations are depicted below using the same methodology as for waste water treatment plants.

Typically the costs of the sewer system amount to 60 to 80% of the total costs of waste water management.

For our calculations the following assumptions were made:

- Depreciation period 50 years
- 75% of the investment costs are due to construction
- out of the construction costs 55% are due to salaries (see chapter 3.2.1)
- operation costs amount to 20% of the total annual costs for the sewer system; 100% personnel costs
- development of salaries: the current difference of salaries will be reduced to zero in 50years
- development of labour productivity: as for wwtps the labour productivity will become equal in 30 years and the subsequent 20 years

The total annual cost for sewer systems compared to Austria are 17% (CZ) to 28% cheaper (SK).

For the calculations of the total annual costs of waste water management the mean total annual cost of CNDP plants were assumed as 20%, 30% respectively 40% of the total annual costs of waste water management. For the assumption that waste water treatment costs amount to 30% total costs 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.

Table 17: Total annual costs of waste water management

total annual costs of waste water management (sewer + wwtp)									
in €/pe.y	A	BG	CZ	HU	RO	SK	SI	TK	UA
CNDP mean annual costs	38	29	31	27	29	28	30	31	28
total costs (sewer 60%)	95	72	78	69	73	71	74	77	69
total costs (sewer 70%)	127	97	104	92	97	94	99	103	92
total costs (sewer 80%)	191	145	156	137	146	141	148	154	138

4 Case study on nutrient reduction in industry

Nutrient emissions from industrial dischargers which are discharged directly to the surface waters are captured within the Danube basin by the ICPDR emission inventory. This emission inventory aims to cover the most important industrial facilities with their annual loads directly discharged to the surface waters in terms of discharged water volume and the respective loads of BOD_5, COD, Tot-N and Tot-P.

For the Danube countries Austria, Hungary, Romania and Bulgaria of which large parts of the national territories are situated in the Danube river basin, the annual Tot-N and Tot-P loads from industrial facilities listed in the ICPDR emission inventory were compared to annual Tot-N and Tot-P loads from point sources as well as to annual Tot-N and Tot-P river loads. This comparison is shown in **Error! Reference source not found.**.

Table 18: Annual TN and TP emissions from industrial discharges in comparison to annual TN and TP emissions from point sources and total TN and TP emissions to surface waters for Austrian, Hungarian, Romanian and Bulgarian areas of the Danube river basin

	Total emissions from industrial discharges		**Total emissions from point sources**		**Total nutrient emissions to surface waters**		**Share industrial emissions on total point source emissions**		**Share point source emissions on total emissions**	
	Tot-N. [t N/a]	**Tot-P.** [t P/a]	**Tot-N.** [t N/a]	**Tot-P.** [t P/a]	**Tot-N.** [t N/a]	**Tot-P.** [t P/a]	**Tot-N.** [%]	**Tot-P.** [%]	**Tot-N.** [%]	**Tot-P.** [%]
Source:	ICPDR emission inventory		[Schreiber et al. 2003]		[Schreiber et al. 2003]					
Austria	831	103	16,050	2,108	80,600	7,126	**5**	**5**	**20**	**30**
Hungary	1,315	50	15,930	2,994	45,210	6,991	**8**	**2**	**35**	**43**
Romania	4,222	25	30,780	4,462	163,530	16,007	**14**	**1**	**19**	**28**
Bulgaria	832	45	9,420	2,099	44,800	5,214	**9**	**2**	**21**	**40**

Annual total nitrogen emissions to surface waters from industrial facilities range between **5-14%** of total nitrogen emissions from point sources, annual total phosphorus emissions are within a range of **1-5%** of the total phosphorus emissions from point sources in the regarded countries. Although the database (ICPDR emission inventory 2002) cover only the major industrial dischargers to surface waters for specific countries of the Danube river basin and in addition not for every industrial facility data on Tot-N and Tot-P loads are available, it is obvious that industrial facilities with direct discharges to the surface waters are responsible for less than 20% of TN emissions by point sources and for less than 10% of TP emissions by point sources to the surface waters.

Highest fractions of TN emissions can in general be associated to discharges from chemical industry, fertiliser industry, food and leather industry. Highest fractions of TP emissions were predominantly caused by discharges from food industry, chemical industry and pulp & paper industry.

Total point source emissions of TN and TP in turn cause between **19-35%** and **28-43%** of total TN and TP emissions to surface waters, respectively of the selected countries.

Emissions from industrial discharges directly to surface waters have been significantly higher in the end of the 1980ies. In IWAG (1997) direct discharges from industry to surface waters of 17 ktN/year, 13 ktN/year and 4 ktN/year as well as 1.6 ktP/year, 0.6 ktP/year and 0.5 ktP/year were evaluated for Romania, Bulgaria and Hungary, respectively at the national level for 1988/1989. At this time, industrial facilities in general and fertiliser production facilities in particular contributed considerably to total nitrogen and phosphorus emissions to surface waters because of no emission standards and no emission abatement techniques, which have been applied to the industrial facilities. Due to the economic collapse in these countries after 1990 many large industrial facilities have been closed or had to be reconstructed (renovated) to be able to compete on the new market with other international establishments. This resulted also in a considerable decrease in nitrogen and phosphorus emissions to surface waters from industrial facilities because of an improved environmental performance of the still existing, upgraded or newly constructed facilities.

In terms of measures, which have a significant potential to reduce nutrient emissions to surface waters the industrial facilities will be of minor importance, when total nutrient emissions from point sources should be reduced on the national scale or on the (large) river basin scale as the environmental performance of industrial facilities is also of economic importance. Excluded in this respect are facilities which do not have applied BAT for emission reduction yet, they are likely offer high potential for reduction of nutrient emissions to surface waters. Anyhow, some industrial branches are characterised by considerable nitrogen and/or phosphorus emissions due to high production capacities, even if specific emissions (kg emission per ton of product) kept as low as possible (by introduction of emission abatement techniques according to BAT), and these facilities may have a significant local impact on nutrient emissions particularly if smaller surface water bodies with limited river discharges receive the industrial discharges.

In regard to nutrient emissions, which will be discharged to the surface water and which are subject of transnational transport to the receiving coastal waters, industrial facilities offer only limited possibilities to introduce measures for nutrient emission reduction, which will have high potential to reduce total nutrient emissions with comparatively low / moderate effort. Most industrial facilities (within the EU) have to fulfil the obligations of the IPPC directive, which aims to reduce emissions to the air, the soil and the water. Anticipated emission levels can be associated with best available techniques (BAT), which implies partly the introduction of recycling operations for selected industrial branches and production processes, what improves significantly the environmental performance of industrial facilities by saving input materials (water, recycled goods) as well as by reducing emissions to the environment to an accepted level. For new plants /production facilities the consideration of BAT techniques for emission abatement is state-of-the-art and possible with an adequate cost-effectiveness. The adaptation of older production facilities is not always that easy and may result in limited applicability of BAT measures (e.g. due to obsolete production techniques). These older facilities can then be of particular interest because they will have the highest potential for measures for (nutrient) emission reductions both to the air and to the water.

4.1 Cost-effectiveness calculations for fertilizer industry

4.1.1 General remarks and considerations

Fertilizer industry was investigated in terms of production of straight N-fertiliser, straight P-fertilizer and multi-nutrient fertilizer (NP-, NPK-, PK-fertilizer). Investigations were grouped in respect to:

- Production of N-based fertilizer
- Production of P-based fertilizer

One case study production facility either for the production of N- or P-based fertilizers was investigated for the determination of specific waste water emissions from individual production lines (production of different fertiliser types). Literature values were used to confirm the specific waste water emissions of different production lines and to define waste water emission levels according to the implementation of best available techniques (BAT). BAT emission levels were defined as reference values, which can be expected for nutrient emissions from waste water discharges.

Annual nutrient emissions of different production lines according to BAT emission levels were calculated with production capacity of case study plants (see Table 19) to ensure comparability with current emissions from the case study plants.

Table 19: Production capacities of case study plants (rounded), which have been used to calculate annual emissions

Production of	Production line	Production capacity [t/a]
N-based fertiliser	Production of ammonia	**450,000**
	Production of AN/CAN	**370,000**
	Production of MN fertiliser (ODDA process) [kg/t P_2O_5]	**325,000**
	Production of Urea/UAN	**400,000**
P-based fertiliser	Production of SSP/TSP for MN fertiliser (mixed acid route)	**56,000**

Data about costs of industrial production processes is very sensitive information in terms of competition. Investigations on investment and operating costs concentrated therefore on costs which can be associated with introduction of BAT measures for reduction of emissions to air and to running waters. For the regarded case study plants only limited information about investment costs and operating costs could be obtained. The majority of used information about costs was obtained from the literature. This information represents a very rough estimation with high uncertainty because of the following reasons:

- potential differences in production processes for different plants
- often information on investment costs are given as a whole estimate - they do not provide additional information on considered specific production or emission abatement technology
- operating costs are mostly estimated as fraction of total investment costs (between 4. and 10% of investment costs)

For calculation of cost-effectiveness only costs were considered which could be **associated with emission reduction to air** (main source of waste water generation in fertiliser production) **and with abatement of wastewater emissions to surface water** (measures to reduce nutrients discharged with waste water).

Waste water emissions in fertilizer production originate mainly from:

- wet scrubbing of process off-gases (to conform with emission limits to air)
- condensates from production process
- washing liquors

Data on investment costs and operating costs for the implementation of BAT could be obtained for all production lines with different spread (at least one estimation for each production line). If data about investment costs obtained from literature were based on production capacities which exceeded the capacity of the case study plant considerably, estimates on investment costs for the case study plants were downgraded according to the production capacity of case study plant. Investment costs and operating costs of case study plants were estimated based on best guesses and information about used emission abatement technology and costs estimations from available information (e.g. for waste gas scrubbing systems (used in almost all production lines) available information on investment costs were transferred also to production other production lines and were up- or downgraded according to the waste gas volumes).

Investment costs were annualised according to equation in chapter 3.2.3.1 of draft methodological report by the following equation:

$$a = C_0 \frac{q^n (q-1)}{q^n - 1} \qquad \text{eq. 3.1}$$

with

$$q = i + 1 \qquad \text{eq. 3.2}$$

a… annuity (annual capital costs)
C_0.. total investment costs
i… real discount rate (**5%**)
n... number of years (**20 years**)

Annualised investment costs and annual operating costs were summed up to total annual costs, which have been used for cost-effectiveness-calculations.

4.1.2 Production of P-based fertilizers

4.1.2.1 Production of MN fertiliser by mixed acid route

Production of P-based fertilizers by the mixed acid route involves two major production steps:

- Production of Single Superphosphate (SSP) / Triple Superphosphate (TSP)
- Production of multi-nutrient (MN) fertilizer by mixed acid route (NPK-, PK-fertilizer) using SSP/TSP or phosphoric acid

Superphosphates are defined by the percentage of phosphorus as P_2O_5 and are used as straight fertilisers and also as a feedstock for multi-nutrient (MN) fertiliser production. Single superphosphate (SSP) and triple superphosphate (TSP) are mainly used for the production of NPK-(Nitrogen-Phosphorus-Potassium) or PK-(Phosphorus-Potassium) fertilisers. SSP and TSP are manufactured treating phosphate rock with either sulphuric acid (SSP) or phosphoric acid (TSP).

Waste water emissions arise from **scrubbing liquors** from waste gas scrubbing during SSP/TSP production. Waste water contains phosphates, nitrogen and fluorine compounds, sulphates and heavy metals. Considerable discharges of highly toxic fluosilicic acid with wastewater are of particular environmental concern.

Waste water emissions from the production of MN-fertilisers by mixed acid route can totally be avoided when scrubbing solutions from waste gas scrubbing are recycled into the production process. Therefore it will be assumed that no waste water emissions will arise from MN fertiliser production by mixed acid route, when BAT are applied.

From specific waste water emissions of the case study plant annual nitrogen and phosphorus loads from waste water discharges were calculated. They were compared to specific waste water emissions and calculated annual nitrogen emission levels according to BAT emission levels (Table 20).

Table 20: Comparison of specific emissions and annual loads from case study plant with emission levels according to BAT for production of MN-fertiliser by mixed acid route (production capacity: appr. 56,000 t/year SSP/TSP; BAT emission levels are given for NPK production only – total annual emissions according to BAT were calculated based on production capacity for MN fertiliser)

	Current emissions - case study plant		**BAT emission levels**
	N	**P**	**N**
			*[kg/t NPK]
specific emissions (production of SSP/TSP: P_2O_5-content 19%, 49% resp.) [kg/t P_2O_5]	**1.7**	**0.59**	**0.2***
annual loads [kg/a]	**20815**	**7224**	**31600**

*…MN fertiliser production capacity: 158,000 t/year

Waste water emissions arise during SSP/TSP production but the further processing to MN fertiliser will not produce further wastewater these emissions can be compared to BAT emission levels available for NPK production (production of MN fertilisers by mixed acid route). For the regarded case study plant annual loads of nitrogen are 30% lower than annual loads calculated from BAT emission levels (Table 20). For phosphorus no BAT emission levels are given for NPK production although waste water emissions contain P.

Data on investment costs were available for NPK production only. Since waste water is assumed to arise only from SSP/TSP production, for the case study plant investment costs have been estimated for implementation of waste gas treatment of SSP/TSP production only. Literature values on costs were obtained for MN fertiliser production by mixed acid route only. Table 21 compiles these information with calculated total annual costs and specific costs per ton of fertiliser produced.

Table 21: Calculation of total annual costs and specific costs per ton fertiliser produced for emission reduction for NPK production by mixed acid route (1-4) and for SSP/TSP production (5) (Source of information: (EFMA 2000), (Umweltbundesamt 2002))

Equipment	Annual capital costs [€/a]	Operating costs[1] [€/a]	Total annual costs [€/a]	Costs vs. amount fertiliser produced [€/t product]
1.) BAT equipment, integrated in new plants (3 mio €), capacity 350,000 t/a [NPK]*	**168,509**	**150,000**	**318,509**	**2.02**
2.) BAT equipment, added later to existing plants (5 mio €), capacity 350,000 t/a [NPK]*	**280,849**	**150,000**	**430,849**	**2.73**
3.) BAT equipment, liquid waste treatment (2 mio €), capacity 350,000 t/a [NPK]*	**112,340**	**150,000**	**262,340**	**1.66**
4.) NPK plant (30 mio€); 20% pollution abatement equipment, capacity 350,000 t/a [NPK]*	**337,019**	**150,000**	**487,019**	**3.08**
5.) Waste gas scrubbing for SSP/TSP production - estimated	**120,364**	**60,000****	**180,364**	**1.14**

*…Source: [EFMA 2000]

**… estimated to 4% of investment costs

[1]…Operating costs: 1€/t;

Investment costs of first examples 1-4 in Table 21 correspond to a MN fertiliser production with production capacity of 350,000 t NPK per year. Since production capacity of the case study plant is about 160,000 t/a data on investment costs were downgraded by 30% before annualisation as they were related to wastewater emissions and fertiliser production capacity of the case study plant. Operating costs of literature values were given as about 1€/t of product. Example 5 in Table 21 represents estimates on investment costs and operating costs for waste gas scrubbing for SSP/TSP production of the case study plant.

Calculated total annual costs for BAT measures to reduce waste water emissions to surface waters range between 262…487 T€. From data about investment costs of introduction of BAT can be obtained that in general the construction of new plants with integrated BAT technology results in lower specific investment costs for emission abatement than upgrading existing plants to BAT levels. Treatment of liquid waste effluents was given as the example with lowest investment costs. Estimates for the case study plant resulted in lower total annual costs of about 180 T€ what gives hints that investment costs for emission abatement were underestimated. Total annual costs related to annual fertiliser production capacity range between 1.1…3.1 €/t of product.

4.1.2.2 Production of phosphoric acid and sulphuric acid

As main starting materials for the production of SSP, TSP and MN fertiliser phosphate rock, sulphuric acid (H_2SO_4) and phosphoric acid (H_3PO_4) is used. Although phosphoric acid is not produced in the regarded case study plant, production of phosphoric acid in general produces wastewater emissions containing phosphates, fluorine, cadmium, mercury, arsenic and other heavy metals (digestion of phosphate rock). Phosphate (P) emissions to water from production of phosphoric acid are reported to amount to **0.7-1.3 kg/t P_2O_5**.

The production of phosphoric acid is also associated with considerable amount of gypsum generated, which contain also considerable amounts of phosphates. Reported emission levels for the disposal of phosphogypsum to water from the production amount to **4-4.7 t/t P_2O_5 gypsum** and **5.8-8.1 kg/t P_2O_5 phosphate (P)**.

For new plants a closed loop system with full recycling of liquid effluents to the process is possible. For existing plants open loop system can be converted to close loop systems, if not adequate treatment before disposal is to be sought. BAT emission levels could not be obtained for liquid effluents.

4.1.3 Production of N-based fertilizers

4.1.3.1 Ammonia production

Ammonia is an intermediate product and required for the production of various straight nitrogen fertilizers. About 97% of the nitrogen fertilizers such as urea, ammonium-nitrate (AN) and calcium-ammonium-nitrate (CAN) are derived from ammonia. Ammonia is also used for the production of multi-nutrient fertilizers (NP- and NPK-fertilizer)

Waste water emissions during ammonia synthesis originate from condensates from synthesis section (condensation section). Condensate (1-1.5 m^3/t) contains about 1 kg/m^3 of each NH_4 and methanol. Treatment of condensates using process stream (stripping) can reduce emissions by about 95%. In Annex 6.2 specific waste water emissions from ammonia case study plant are listed.

Table 22 shows specific nitrogen emissions with process waste water from raw condensates (before treatment) and achievable emissions according to BAT and by advanced treatment (condensate stripping and recycling). From case study plant no specific waste water emissions could be obtained as available information characterised the waste water emissions before a treatment unit (the implementation of stripping unit for waste water treatment has been finished in the meantime).

Table 22: Comparison of specific emissions and annual loads from case study plant with emission levels according to BAT and for advanced treatment for production of ammonia (production capacity: appr. 450,000 t/year NH_3)

	Condensate (before treatment)	BAT emission levels	Advanced treatment: Stripping + Recycling	Emission reduction to achieve BAT	Emission reduction - advanced treatment
	N	N	N	N	N
specific emissions [kg/t NH_3]	1.2	0.1	0.028	1.10	1.17
annual loads [kg/a]	537,930	44,828	12,552	493,103	525,378

Using advanced treatment achievable specific emission levels can be lower than emission levels according to BAT. Related to condensate concentration before treatment, emission reduction down to BAT emission levels reduces nitrogen emissions to surface water by 92% (specific reduction of N emissions: 1,1 kg/t NH_3), with implementation of advanced treatment using condensate stripping and recycling even by 98% (specific reduction of N emissions: 1,17 kg/t NH_3).

Also for ammonia production data on investment costs are very limited and uncertain. Process condensate recycling for bringing existing plants to BAT emission levels is roughly anticipated with investments of 2.9-3.3 mio €. For the case study plant estimates on emission abatement technology were made based on available information on treatment technology (waste gas scrubbing, stripping unit). Calculated total annual costs as well as specific costs for reduced emissions (from condensate to BAT/ reduced emission levels using stripping + recycling) are shown in Table 23.

Table 23: Calculation of total annual costs for emission reduction, costs per kg of emissions reduced and specific costs per ton fertiliser produced for ammonia production (Source of information: (EFMA 2000), (Umweltbundesamt 2002))

Equipment	Annual capital costs	Operating costs[1]	Total annual costs	Costs vs. N emissions reduced (BAT)	Costs vs. N emissions reduced - advanced	Costs vs. amount fertiliser produced
	[€/a]	[€/a]	[€/a]	[€/kg]	[€/kg]	[€/t product]
1.) Process condensate recycling added later to achieve BAT (2,9-3,3 mio€)*	264,801	132,000	396,801	0.80	0.76	0.89
2.) waste gas scrubbing + stripping unit - estimated	280,849	140,000	420,849	0.85	0.80	0.94

*…Source: [EFMA 2000]

[1]…Operating costs: 4% of investment costs

Calculated total annual costs for upgrading existing plants to achieve BAT emission levels were about 397 T€ what is in the same range with estimates on calculated total annual costs for case study plant with 421 T€. Total annual costs for emission reduction related to annual fertiliser production capacity range between 0.89…0.94 €/t of product.

4.1.3.2 Production of MN-fertilizers by nitrophosphate route

Producing MN-fertilizer using the nitrophosphate route requires higher investment and integration with other fertiliser production, but it offers the option to increase the P content in the product without using phosphoric acid. In the nitrophospate process all nutrients are totally used in the production of nitrate containing fertilisers, but this process is restrictive in the sense that only nitrate-containing fertilisers can be produced. This needs a high integration of different plants (e.g. of ammonia plant) and corresponding investments.

Sources of waste water emissions from MN fertiliser production by nitrophosphate route are process condensates from neutralisation/evaporation unit and scrubbing liquors from off-gas treatment of rock digestion and granulation, and washing liquors from sand washing. Waste water contains ammonia, nitrate, fluoride, phosphates and heavy metals.

Ammonia emissions occur when not all condensates of ammonium nitrate from evaporation/neutralisation can be recycled. Nitrate emissions originate mainly from scrubbing liquors of rock digestion and sand washing. Phosphates originate mainly from sand washing.

Scrubbing liquor from rock digestion, sand washing and filtration of CNTH can totally be recycled into the production process and results in a reduction of N emissions (see “advanced treatment - recycling” in Table 24). Recycling of sand washing liquor results in a reduction of P emissions (see Table 24). Not avoidable waste water emissions are discharged into running waters. Specific waste water emissions from MN fertiliser production by nitrophosphate route from case study plant are shown in Annex 6.2.

From specific waste water emissions of case study plant annual nitrogen and phosphorus loads with waste water to surface water were calculated and compared to annual nitrogen and phosphorus loads according to BAT emission levels (see Table 24). When recycling operations are introduced (advanced treatment) lower annual nitrogen and phosphorus loads with waste water can be obtained what offers the opportunity to reduce total annual nitrogen and phosphorus emissions by 50% and 95%, respectively in relation to BAT emission levels (Table 24).

Table 24: Comparison of specific emissions and annual loads from case study plant with emission levels according to BAT and for advanced treatment for production of MN-fertilisers by nitrophosphate route (production capacity: appr. 325,000 t/year NPK (P2O5-content: 28%))

	Current emissions case study plant	Current emissions case study plant	BAT emission levels - NP production		Emission levels advanced treatment: recycling	
	N	P	N	P	N	P
specific emissions [kg/t P_2O_5]	0.66*	0.07	1.2	0.40	0.6	0.02
annual loads [kg/a]	60,667	6,517	109,200	36,400	54,600	1,820

*…NH_4-N + NO_3-N

Current annual nitrogen and phosphorus emissions from case study plant are lower than

BAT associated emission levels. In terms of advanced treatment by recycling of scrubbing liquor and washing liquor there is still potential for the emissions from case study plant to be reduced for both nitrogen (by about 10% referring to current emissions) and phosphorus (by about 70% referring to current emissions).

Data about investment costs for MN fertiliser production were very rare. In comparison to MN-fertiliser production by mixed acid route, production by nitrophosphate route requires higher investments. According to (EFMA 2000) a NPK plant with capacity of 350,000 t/year require investments of about 80-100 mio €. BAT emission abatement equipment was given to be about 20% of total investment costs, what was assumed for cost-emission calculations. Estimates for investment costs of case study plant are based on data about investments in waste gas scrubbing systems, the obtained costs were increased by 50% to consider other equipment (e.g. recycling…). Calculated total annual costs and specific costs per ton of MN fertiliser produced by nitrophosphate route are shown in Table 25.

Table 25: Calculation of total annual costs for emission reduction and specific costs per ton fertiliser produced for MN fertiliser production by nitrophosphate route (Source of information: (EFMA 2000), (Umweltbundesamt 2002))

Equipment	Annual capital costs [€/a]	Operating costs[1] [€/a]	Total annual costs [€/a]	Costs vs. amount fertiliser produced [€/t product]
1.) BAT pollution abatement equipment (20% of total investment costs of NPK plant) = 16 mio€*	1,283,881	1,600,000	2,883,881	8.87
2.) as 1.) - but with recycling operation (20 mio€)	1,604,852	2,000,000	3,604,852	11.09
3.) combined waste gas scrubbing neutralisation/evaporation and granulation; rock digestion - estimated	794,402	990,000	1,784,402	5

*…Source: [EFMA 2000]

[1]…Operating costs: 10% of investment costs

Calculated total annual costs of pollution abatement equipment of a NPK plant (example 1 from Table 25) were about 2.8 mio€/year what is considerably higher than total annual costs for MN fertiliser production by mixed acid route (see chapter 2.2). For the introduction of advanced treatment by recycling operation total investment costs were increased by 25% what resulted in total annual costs of 3.6mio €/year. Estimates for investment costs of case study plant resulted in total annual costs for emission abatement of 1.8 mio €/year. Due to high investment costs for NPK production by nitrophosphate route and emission abatement measures, total annual costs related to annual fertiliser production capacity ranged between 5.5…11 €/t of product.

4.1.3.3 Production of ammonium nitrate (AN) and calcium ammonium nitrate (CAN)

Ammonium nitrate (AN) is used extensively as a nitrogenous fertilizer. It is made by the reaction between gaseous ammonia and aqueous nitric acid (pressure neutralisation) or by conversion of calcium nitrate tetra hydrate (CNTH), which is obtained as a by-product of the ODDA process (MN fertiliser production by nitrophosphate route). The resultant AN can be:

- stored as solution and used in down-stream (other plants)
- formed into solid ammonium nitrate by prilling or granulation
- mixed with a solid filler (most common filler is calcium carbonate to make “calcium ammonium nitrate” (CAN)) and then prilled or granulated

CAN is the most applied fertiliser product in Western Europe.

Sources for waste water emissions from the production of AN are process waters from condensed steam from pressure neutralisation reactor and exhaust vapours from evaporation of AN solution. Liquid effluent usually do not arise from waste gas scrubbing of granulation and drying as scrubbing liquors can be recycled into other fields of fertiliser production. Main pollutants of waste water are ammonium and nitrate.

By recirculation of concentrated process effluents ammonia and AN can partly be recycled into the synthesis section. Purified process condensate can be used for waste gas scrubbing or can be recycled in other plants. Process water that cannot be recycled is discharged.

Scrubbing liquors which arise from the waste gas treatment of granulation of CAN can be recycled into the production process. That means that from production of CAN (processing of AN to CAN) no waste water is discharged.

Waste water emissions from AN pressure neutralisation of the case study plant are shown in Annex 6.2.

From specific waste water emission of the case study plant annual nitrogen emissions with waste water were calculated and compared to annual nitrogen emission according to BAT emission levels (see Table 26).

Table 26: Comparison of specific emissions and annual loads from case study plant with emission levels according to BAT for production of AN (production capacity: 375,000 t/year AN)

	before treatment	Current emissions case study plant	BAT emission level - new plants	Emission reduction to current emissions	Emission reduction to achieve BAT level
	N	N	N	N	N
specific emissions [kg/t AN]	**9**	**0.009**	**0.2**	**8.99**	**8.80**
annual loads [kgN/a]	**3,348,000**	**3,307**	**74,400**	**3,344,693**	**3,273,600**

Annual nitrogen emissions from case study plant are considerably lower than annual nitrogen emissions calculated according to the BAT emission levels using the same production capacity.

Available information about investment costs for AN/CAN production were obtained from (EFMA 2000) too. Two examples were considered: The first is called minimisation within the plant: Concentration of neutraliser condensate by reverse osmosis, ion exchange and evaporation. Two streams will be the result: one concentrated and one “cleaned”. Investment costs will be about 1-2 mio € (capacity 1500 t/d of AN).

As second example end-of-pipe-treatment was selected using air and stream stripping and ion exchange. Steam stripping will require the addition of alkali to liberate free ammonia and will not reduce the nitrate content of the effluent! Investment costs will be 1-3 mio €.

For the case study plant investment costs were estimated based on information of involved equipment for air emission abatement. Calculated total annual costs, specific costs per ton of fertiliser produced and costs related to emissions reduced to achieve BAT emission level or current emission levels of the case study plant are shown in Table 27.

Table 27: Calculation of total annual costs for emission reduction, cost per kg of emissions reduced and specific costs per ton fertiliser produced for AN production (Source of information: (EFMA 2000), (Umweltbundesamt 2002))

Equipment	Annual capital costs	Operating costs[1]	Total annual costs	Costs vs. N emission reduction to emissions csp	Costs vs. N emission reduction to BAT	Costs vs. amount produced fertiliser
	[€/a]	[€/a]	[€/a]	[€/kg]	[€/kg]	[€/t product]
1.) Concentration of condensate from neutraliser by reverse osmosis, ion exchange, evaporation (two streams: one concentrated, one cleaned) - capacity 1500 t/d (2 mio€)*	**160,485**	**80,000**	**240,485**	**0.07**	**0.07**	**0.65**
2.) end-of-pipe treatment **for existing plants** (Stripping + ion exchange) **except for prilling plants** (3 mio€)*	**240,728**	**120,000**	**360,728**	**0.11**	**0.11**	**0.97**
3.) waste gas scrubbing, removal of AN and NH_3 from condensate and recycling - estimated	**308,933**	**153,700**	**462,633**	**0.14**	**0.14**	**1.24**

*…Source: [EFMA 2000]

[1]…Operating costs: 4% of investment costs

Calculated total annual costs for emission reduction measures to achieve BAT emission levels were about 240 T€. Second example (end-of-pipe treatment) resulted in total annual costs of 360 T€. For both examples the upper limit of investment costs were used for the calculations. Estimates on investment costs for emission abatement of case study plants resulted in calculated total annual costs of about 460 T€, what indicates that investment costs for emission reduction to surface water were overestimated. One the other side, current emission from case study plant are considerable lower than BAT emission levels what could be the result of higher investments and higher total annual costs for emission reduction in comparison to BAT measures. Total annual costs related to the production capacity ranged between 0.65…1.2 €/t of product.

4.1.3.4 Production of urea and urea ammonium nitrate (UAN)

Urea has become the most used solid nitrogen fertiliser in the world, mainly because of its use for flooded rice. Urea is also used in melamine manufacture, for various urea/formaldehyde resins/adhesives and as cattle feed supplement (inexpensive N source).

Waste water emissions originate from process condensate (about 0.3 m^3/t U) from which the main part arises in evaporation unit. It contains large amounts of NH_3, urea (NH_3- and urea-content 6% and 1% by weight) and CO_2, which are recovered from the process condensate and recycled to the synthesis section.

For recovery of NH_3 and CO_2 from process water different treatment systems are available. Using desorption-hydrolysis-systems or distillation-hydrolysis-systems NH_3 and CO_2 is eliminated from process water via stripping/distillation and will be recycled to the production process. Hydrolysis sections are used for decomposition of remaining urea and for subsequent recovery of NH_3 and CO_2. With both systems concentrations of 5 mg/l NH_3 and 1 mg/l urea can be expected. Using stripping-hydrolysis-systems free NH_3 and urea concentrations of 3-5 mg/l each are expected.

Existing plants show varying values for emissions into water after process water treatment of 20-230 mg/l NH_3 (0.01-0.61 kg NH_3/t of product) and 20-320 mg/l urea (0.01-0.84 kg urea/ t of product).

Waste water emissions from urea production of case study plant are shown in Annex 6.2.

From specific waste water emissions of the case study plant annual nitrogen emissions to surface water were calculated and compared to annual nitrogen emissions calculated according to the BAT emission levels for new plants for upgraded existing plants (see

Table 28).

Table 28: Comparison of specific emissions and annual loads from case study plant with emission levels according to BAT for production of Urea/UAN production (production capacity: 400,000 t/year urea)

	before treatment	Current emissions case study plant	BAT emission level - new plants	BAT emission level - existing plants	Emission reduction to achieve BAT level -new plants	Emission reduction to achieve BAT level -existing plants
	N	N	N	N	N	N
specific emissions [kg/t U]	21	0.19	0.002	0.1	20.998	20.9
annual loads [kgN/a]	4,440,000	77,143	873	42,404	4,439,127	4,397,596

Current emissions from case study plant exceed BAT emission levels for upgrading existing plants by about 80%, what indicates need for action in terms of reducing nitrogen loads via waste water emissions. For new plants integrated pollution abatement technology is very efficient in terms of the reduction of nitrogen loads via waste water to surface waters. Annual nitrogen loads with waste water emissions according to BAT emission levels will result in total annual emission of about 2% in comparison to annual emissions according to BAT emission levels for existing plants. This offers high potential for measures to reduce nitrogen emissions in case that old existing plants will be completely replaced by new plants.

Information about investment were obtained from (EFMA 2000). Two example for upgrading existing plants to BAT levels are given in the following way: one example is given which aims at treating and recovery of nutrient from prill tower effluents what would require investments of at least 6.25 mio €. Another example gives investment costs for installation of liquid spillage recovery system, solids recovery and additional process waste water holding capacity (3x plant inventory) of up to 2.5 mio €. Estimates of investment costs for waste water treatment of case study plant range within the order of magnitude of the investment costs of the second example.

In Table 29 calculated total annual costs, specific costs per ton of fertiliser produced and costs related to emissions reduced are shown. As both data about investment costs were given for upgrading existing plants no costs per emissions reduced to achieve BAT emission levels of new plants could be calculated.

Table 29: Calculation of total annual costs for emission reduction, costs per emissions reduced and specific costs per ton fertiliser produced for Urea production (Source of information:(EFMA 2000), (Umweltbundesamt 2002))

Equipment	Annual capital costs	Operating costs[1]	Total annual costs	Costs vs. N emission reduction (BAT-existing)	Costs vs. amount produced fertiliser
	[€/a]	[€/a]	[€/a]	[€/kg]	[€/t product]
1.) treatment and recovery of nutrients from prill tower effluent (6,25 mio€)*	501,516	312,500	814,016	0.19	2.04
2.) liquid spillage recovery, solids recovery, additional process waste water capacity*	200,606	125,000	325,606	0.07	0.81

*…Source: [EFMA 2000]

[1] …Operating costs: 5% of investment costs

Total investment costs about opportunities for nutrient emission reduction via waste water discharges range considerably and no concrete information is available, whether this opportunities decrease nutrient from waste water via condensate treatment. Anyhow, calculated total annual costs for emission reduction to achieve BAT emission levels for upgraded existing plants range between 325…814 T€. Complete replacement of an old plant by a new one will result in considerably higher investment costs, but on the other side total nitrogen emissions by waste water discharges can be reduced considerably too, but this scenario could not be regarded as no information on total investment costs of such a measure are available.

Calculated total annual costs related to annual fertiliser production capacity ranged between 0.8…2.0 €/t of product.

4.1.4 Summary

For each fertiliser production line total annual emissions of nitrogen and/or phosphorus were calculated based on specific emissions (kg/t) for the case study plants based on production capacities as well as total annual emissions which can be associated with the application of BAT using those capacities.

For cost-effectiveness-considerations the following information are of particular interest to be able to compare the effectiveness of nutrient reduction measures with measures in other sectors (e.g. municipal wastewater treatment). These are:

- how much is the reduction of nutrient emissions with the measure (in this case the reduction of nutrient emissions in liquid effluents from untreated status to BAT emission levels (or levels which can be reached via application of advanced treatment)
- what are the total annual costs of measures which can be associated to this emission reduction
- what is the specific nutrient emission based on the production capacity to be able to calculate total annual emissions using variable production capacities

In comparison to municipal wastewater treatment sector, comparability of cost-effectiveness will be possible only using cost-effectiveness-ratios calculated for the reduced annual nutrient emissions related to total annual costs. As information on nutrient concentrations in process waters in untreated status were available only for three production lines, nutrient emission reduction to achieve BAT emission levels could be calculated for those two production lines only: the ammonia production, the production of AN and the urea production. For these three production lines also cost-effectiveness-ratios were calculated (see Table 30), which can be compared to cost-effectiveness-ratios calculated for municipal wastewater treatment sector. Specific reductions in nitrogen emissions via application of BAT (related to ton of produced) range between 1.1 kgN/t NH_3 produced for the ammonia production and 21 kgN/t U produced for the urea production. Specific costs per kg of N emission reduced for urea production and AN/CAN production are very close and range between 0.07 €/kg N reduced and 0.15/0.19 €/kg N reduced. For ammonia production, specific costs were calculated with about 0.8-0.85 €/kg N reduced (see Table 30).

Table 30: Typical specific reduced emissions (kg N/t) to achieve BAT emission levels in comparison to calculated specific costs per kg reduced N

	Specific reduced emissions to achieve BAT level	Costs vs. emissions reduced to achieve BAT [€/kg red. N]	
	[kg/t]	**from**	**to**
Production of ammonia [kg/t NH_3]	**1.1**	**0.8**	**0.85**
Production of AN/CAN [kg/t AN]	**9**	**0.07**	**0.14**
Production of Urea/UAN [kg/t U]	**21**	**0.07**	**0.19**

Specific nitrogen and phosphorus emissions from different fertiliser production lines, which can be expected after upgrading existing plants via application of BAT are summarised in

Table 31. Specific emissions are compared to specific costs (total annual costs related to annual production capacity) which have been calculated for the different fertiliser production lines based on estimates about the total annual costs and on production capacity of the considered case study plants.

Table 31: Calculated annual nitrogen and phosphorus emissions for the production of N-based and P-based fertiliser for the case study plant, for BAT emission levels and further reduced emissions using advanced treatment technology (production capacities of case study plants used for calculation)

	specific BAT emission levels for upgraded **existing** plants		Specific emissions after advanced treatment		Specific annual costs for emission reduction per ton fertiliser produced [€/t]	
Specific Emissions	**N**	**P**	**N**	**P**	**from**	**to**
Production of ammonia [kg/t NH_3]	**0.1**	**-**	**0.028**	**-**	**0.89**	**0.94**
Production of AN/CAN [kg/t AN]	**0.2**	**-**	**-**	**-**	**0.7**	**1.2**
Production of MN fertiliser (ODDA process) [kg/t P_2O_5]	**1.2**	**0.4**	**0.6**	**0.02**	**5.5**	**11.1**
Production of Urea/UAN [kg/t U]	**0.1**	**-**	**0.002**	**-**	**0.8**	**2.0**
Production of MN fertiliser (mixed acid route) [kg/t P_2O_5]	**0.2**	**-**	**-**	**-**	**1.1**	**3.1**

Specific nitrogen emissions which can be expected with liquid effluents from fertiliser production lines for upgraded existing plants to comply with BAT range between 0.1 kgN/t up to 1.2 kgN/t for MN fertiliser production (ODDA process). Specific phosphorus emissions according to BAT for ODDA process are 0.4 kgP/t.

Nitrogen and phosphorus emissions according to the BAT emission levels for upgraded existing plants can be seen as target levels to conform with minimum requirements for discharges from the fertiliser production facilities to surface waters. Nitrogen and phosphorus emissions from new plants, where BAT was considered for construction and operation, will likely be lower than associated emissions from upgraded existing plants (see e.g. urea production). The application of selected techniques for an improved (advanced) treatment or abatement of liquid effluents is likely to reduce specific N and P emissions from different fertiliser production lines significantly below the specific emission levels associated with BAT (see

Table 31).

As for N most of the fertiliser production lines are characterised by similar specific emissions according to BAT, also the mean specific annual costs related to production capacity are comparable and range for almost all production lines between 0.7 and 3.1 €/t (see Figure 21), except the MN fertiliser production by nitrophosphate route.

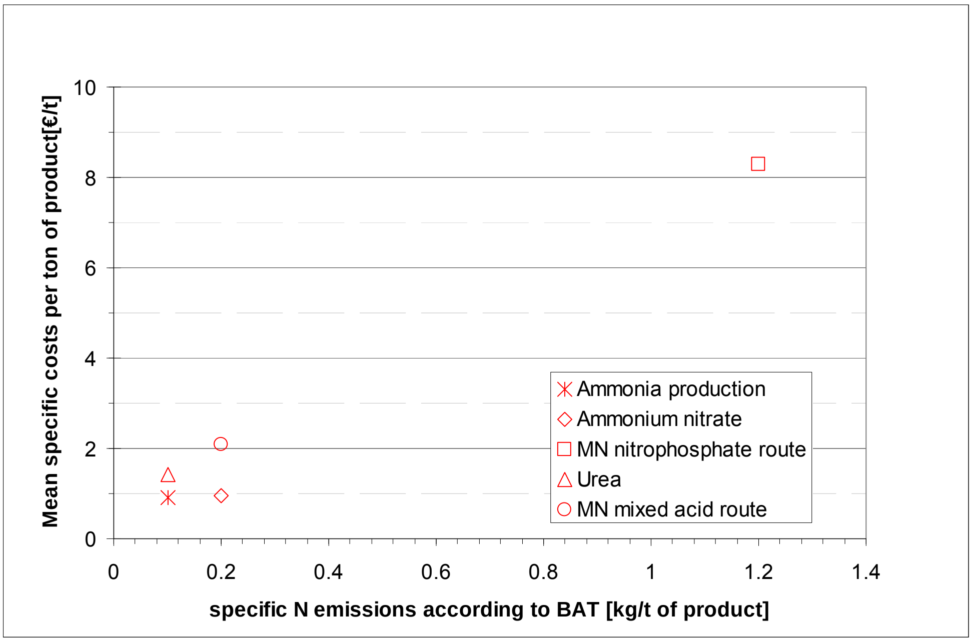

Figure 21: Specific BAT nitrogen emission levels for different fertiliser production lines in comparison to mean specific costs per ton of produced fertiliser

Since for the production of different fertiliser types by individual production lines the interaction between specific production lines is anticipated for recycling operations, flow exchange of input and output materials, energy saving potential (using surplus energy of one production line as energy source in another production line) etc., the production of different N-based or P-based fertiliser will be assumed to be performed at one production facility.

To estimate future N or P emissions from potential fertiliser production facilities, the specific N and P emission levels according to the application of BAT can be used. In terms of potential to reduce N and/or P emissions from selected fertiliser production sites, this depends on the local situation and on the condition of the existing plants. Potential to reduce N and/or P emissions below specific emission levels associated with BAT, special emphasis should be according to

Table 31 particularly on ammonia production, urea production as well as on MN fertiliser production by nitrophosphate route (ODDA process).

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6 Annex

6.1 Municipal

Table 32: Capital cost in €/pe.y for different plant configurations and different design capacities

capital costs in €/pe.y									
CNDP	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
75	47	36	39	34	35	34	37	37	34
250	49	38	41	35	37	36	39	39	35
750	51	39	42	37	38	37	40	40	36
2500	37	29	31	27	28	27	29	29	27
12500	31	24	26	22	23	23	25	25	22
35000	21	16	18	15	16	15	17	17	15
75000	18	14	15	13	13	13	14	14	13
150000	13	10	11	9	10	10	10	10	9
CN plant	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
75	46	35	38	33	34	33	36	36	33
250	48	37	40	35	36	35	38	38	34
750	50	39	42	36	37	36	39	40	36
2500	36	28	30	26	27	26	29	29	26
12500	30	23	25	22	23	22	24	24	22
35000	21	16	17	15	16	15	16	17	15
75000	18	14	15	13	13	13	14	14	13
150000	13	10	11	9	10	9	10	10	9
C plant	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
75	43	33	36	31	32	31	34	34	31
250	45	35	37	32	33	33	35	35	32
750	46	36	39	33	35	34	37	37	33
2500	34	26	28	24	25	25	27	27	24
12500	28	22	24	20	21	21	22	22	20
35000	19	15	16	14	14	14	15	15	14
75000	16	13	14	12	12	12	13	13	12
150000	12	9	10	9	9	9	9	9	9

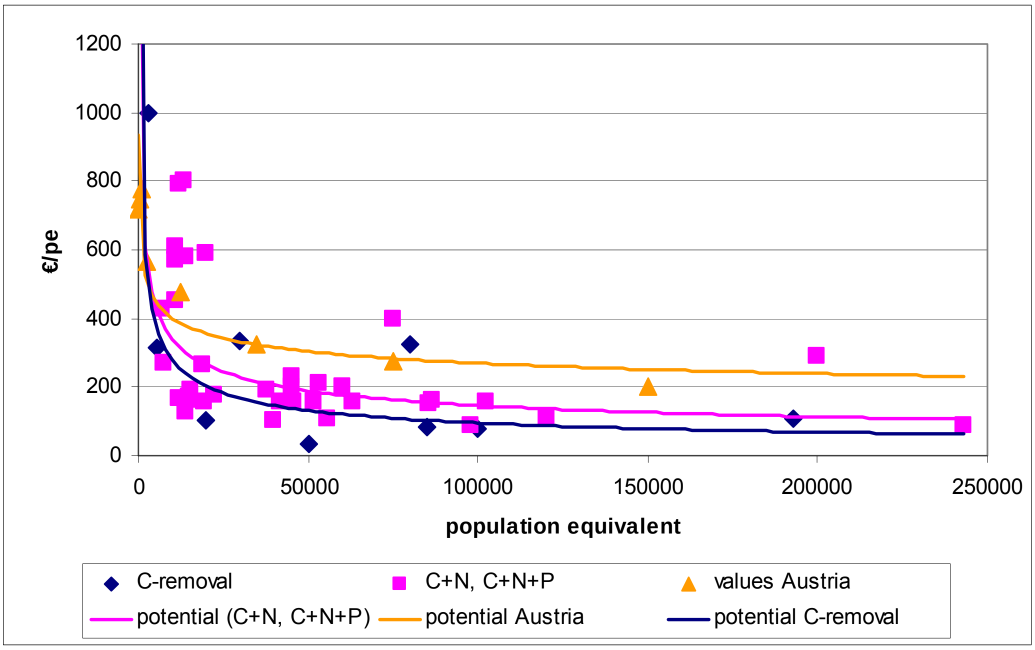

Figure 22: Investment costs for CND- and CNDP-plants in Danubian countries based on the Dablas report and CNDP-plants in Austria

Table 33: cost effectiveness for different plant installations in €/kg N additionally removed

CN-plant -> CND-plant	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
35000	0,5	0,4	0,4	0,3	0,3	0,3	0,4	0,3	0,4
75000	0,4	0,3	0,2	0,2	0,2	0,2	0,2	0,2	0,3
150000	0,2	0,1	0,1	0,0	0,0	0,0	0,0	0,0	0,1
mean	**0,4**	**0,3**	**0,2**	**0,2**	**0,2**	**0,2**	**0,2**	**0,2**	**0,3**
C-plant -> CND-plant	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
35000	1,9	1,5	1,6	1,4	1,5	1,4	1,5	1,6	1,4
75000	1,6	1,2	1,3	1,1	1,2	1,2	1,2	1,3	1,1
150000	1,1	0,8	0,9	0,8	0,8	0,8	0,8	0,9	0,8
mean	**1,5**	**1,1**	**1,3**	**1,1**	**1,2**	**1,2**	**1,2**	**1,3**	**1,1**
no plant -> CND-plant	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
35000	14,9	11,4	12,2	10,7	11,4	10,9	11,5	12,0	10,9
75000	12,5	9,5	10,2	9,0	9,5	9,2	9,7	10,1	9,0
150000	9,4	7,0	7,6	6,7	7,1	7,0	7,2	7,5	6,6
mean	**12,3**	**9,3**	**10,0**	**8,8**	**9,3**	**9,0**	**9,5**	**9,9**	**8,8**
no plant -> CN-plant	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
35000	27,5	20,9	22,5	19,7	21,0	20,2	21,3	22,2	20,0
75000	23,2	17,5	19,0	16,7	17,7	17,2	18,0	18,7	16,7
150000	17,4	13,0	14,3	12,6	13,3	13,0	13,5	14,1	12,3
mean	**22,7**	**17,2**	**18,6**	**16,3**	**17,3**	**16,8**	**17,6**	**18,3**	**16,3**
no-plant -> C-plant	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
35000	50,7	38,6	41,3	36,1	38,5	37,1	39,1	40,7	37,0
75000	42,7	32,4	34,8	30,6	32,4	31,4	33,0	34,3	30,8
150000	32,1	24,0	26,1	23,1	24,3	23,8	24,8	25,8	22,8
mean	**41,8**	**31,7**	**34,1**	**29,9**	**31,8**	**30,8**	**32,3**	**33,6**	**30,2**
no plant -> C-plant	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
35000	143	109	117	102	109	105	110	115	104
75000	120	91	98	86	91	89	93	97	87
150000	90	68	74	65	69	67	70	73	64
mean	**118**	**89**	**96**	**84**	**90**	**87**	**91**	**95**	**85**

Table 34: cost effectiveness for different plant installations in €/kg P additionally removed

no plant -> C-plant	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
35000	143	109	117	102	109	105	110	115	104
75000	120	91	98	86	91	89	93	97	87
150000	90	68	74	65	69	67	70	73	64
mean	**118**	**89**	**96**	**84**	**90**	**87**	**91**	**95**	**85**
no plant -> CNDP-plant	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
35000	76	58	62	55	58	56	59	61	56
75000	64	49	53	46	49	48	50	52	47
150000	49	37	40	35	37	36	38	39	35
mean	**63**	**48**	**52**	**45**	**48**	**47**	**49**	**51**	**46**
C-plant -> CNDP-plant	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
35000	17,0	13,3	14,2	12,8	13,5	13,1	13,5	14,1	12,8
75000	14,6	11,3	12,1	10,9	11,5	11,3	11,5	12,1	10,9
150000	11,5	8,8	9,5	8,7	9,1	9,0	9,1	9,6	8,4
mean	**14,3**	**11,1**	**11,9**	**10,8**	**11,4**	**11,1**	**11,4**	**11,9**	**10,7**
C-plant -> CP-plant	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
	4,3	3,7	3,8	3,6	3,7	3,7	3,7	3,8	3,7

Table 35: relations of costs for sewer system, CNDP plants and the total costs for waste water management

relations A = 100	**A**	**BG**	**CZ**	**HU**	**RO**	**SK**	**SI**	**TK**	**UA**
sewer system	100	81	83	71	78	72	78	82	80
CNDP mean	100	76	82	72	76	74	77	81	73
total ww management	100	79	82	71	77	73	78	81	78

operation costs CNDP		Austria			Bulgaria			Czech Republic			Hungary			Romania		
		25%	Med.	75%	25%	Med.	75%	25%	Med.	75%	25%	Med.	75%	25%	Med.	75%
10000 - 50000 pe in €/pe.a	materials/chemicals	1,5	2,0	3,0	1,5	2,0	3,0	1,5	2,0	3,0	1,5	2,0	3,0	1,5	2,0	3,0
	personnel costs	5,2	6,3	8,5	4,2	5,0	6,8	3,7	4,5	6,1	2,9	3,6	4,8	3,9	4,7	6,3
	external costs	0,9	1,4	2,5	0,6	1,0	1,7	0,7	1,1	1,9	0,6	1,0	1,8	0,6	0,9	1,7
	energy costs	2,3	2,1	3,4	1,4	1,3	2,0	2,3	2,1	3,4	2,4	2,2	3,6	2,5	2,3	3,7
	sludge disposal	1,9	2,7	3,4	1,0	1,4	1,8	1,1	1,6	2,0	1,0	1,4	1,8	1,0	1,4	1,8
	other costs	1,3	1,5	1,9	1,0	1,2	1,5	1,1	1,2	1,6	1,0	1,1	1,4	1,1	1,3	1,6
	total	**13,1**	**16,0**	**22,6**	**9,6**	**11,8**	**16,7**	**10,4**	**12,5**	**17,9**	**9,4**	**11,3**	**16,3**	**10,5**	**12,5**	**18,0**
> 100000 pe in €/pe.a	materials/chemicals	1,3	1,4	1,4	1,3	1,4	1,4	1,3	1,4	1,4	1,3	1,4	1,4	1,3	1,4	1,4
	personnel costs	3,0	3,3	3,2	2,4	2,6	2,6	2,2	2,4	2,3	1,7	1,9	1,8	2,2	2,5	2,4
	external costs	0,9	1,0	1,6	0,6	0,7	1,1	0,7	0,7	1,2	0,7	0,7	1,1	0,6	0,7	1,1
	energy costs	1,9	2,0	1,9	1,1	1,2	1,1	1,9	2,0	1,9	2,0	2,1	2,0	2,1	2,1	2,0
	sludge disposal	1,9	2,7	3,2	1,0	1,4	1,7	1,1	1,6	1,9	1,0	1,4	1,7	1,0	1,4	1,7
	other costs	0,5	0,5	0,6	0,3	0,4	0,5	0,4	0,4	0,5	0,4	0,4	0,5	0,4	0,4	0,5
	total	**9,5**	**10,9**	**12,0**	**6,8**	**7,7**	**8,4**	**7,6**	**8,5**	**9,3**	**7,0**	**7,9**	**8,5**	**7,6**	**8,5**	**9,2**

operation costs C-plant		Austria			Bulgaria			Czech Republic			Hungary			Romania		
		25%	Med.	75%	25%	Med.	75%	25%	Med.	75%	25%	Med.	75%	25%	Med.	75%
10000 - 50000 pe in €/pe.a	materials/chemicals	0,9	1,2	1,8	0,9	1,2	1,8	0,9	1,2	1,8	0,9	1,2	1,8	0,9	1,2	1,8
	personnel costs	4,7	5,7	7,6	3,6	4,4	6,0	3,3	4,0	5,4	2,6	3,1	4,2	3,4	4,1	5,6
	external costs	0,8	1,3	2,2	0,5	0,9	1,5	0,6	1,0	1,7	0,6	0,9	1,6	0,5	0,9	1,5
	energy costs	1,9	1,8	2,9	1,1	1,1	1,7	1,9	1,8	2,9	2,0	1,8	3,0	2,1	1,9	3,1
	sludge disposal	1,5	2,2	2,7	0,8	1,2	1,5	0,9	1,3	1,6	0,8	1,2	1,5	0,8	1,1	1,4
	other costs	1,1	1,3	1,6	0,8	1,0	1,2	0,9	1,0	1,3	0,8	0,9	1,2	0,9	1,0	1,3
	total	**10,9**	**13,3**	**18,8**	**7,8**	**9,6**	**13,6**	**8,5**	**10,1**	**14,6**	**7,6**	**9,1**	**13,1**	**8,6**	**10,2**	**14,7**
> 100000 pe in €/pe.a	materials/chemicals	0,8	0,8	0,9	0,8	0,8	0,9	0,8	0,8	0,9	0,8	0,8	0,9	0,8	0,8	0,9
	personnel costs	2,7	3,0	2,9	2,1	2,3	2,2	1,9	2,0	2,0	1,5	1,6	1,6	1,9	2,1	2,1
	external costs	0,8	0,9	1,4	0,6	0,6	1,0	0,6	0,7	1,1	0,6	0,6	1,0	0,6	0,6	1,0
	energy costs	1,6	1,7	1,6	1,0	1,0	0,9	1,6	1,7	1,6	1,7	1,7	1,6	1,7	1,8	1,7
	sludge disposal	1,6	2,2	2,6	0,8	1,2	1,4	0,9	1,3	1,5	0,8	1,2	1,4	0,8	1,1	1,4
	other costs	0,4	0,4	0,5	0,3	0,3	0,4	0,3	0,3	0,4	0,3	0,3	0,4	0,3	0,3	0,4
	total	**7,8**	**8,9**	**9,9**	**5,4**	**6,1**	**6,7**	**6,1**	**6,8**	**7,5**	**5,6**	**6,2**	**6,8**	**6,1**	**6,8**	**7,4**

operation costs CNDP		Slovakia			Slovenia			Turkey			Ukraine			Germany		
		25%	Med.	75%	25%	Med.	75%	25%	Med.	75%	25%	Med.	75%	25%	Med.	75%
10000 - 50000 pe in €/pe.a	materials/chemicals	1,5	2,0	3,0	1,5	2,0	3,0	1,5	2,0	3,0	1,5	2,0	3,0	1,5	2,0	3,0
	personnel costs	3,0	3,7	4,9	3,4	4,1	5,5	4,0	4,9	6,5	4,9	5,9	7,9	5,6	6,8	9,1
	external costs	0,6	1,0	1,8	0,7	1,1	1,9	0,6	1,0	1,7	0,6	0,9	1,6	0,9	1,4	2,5
	energy costs	2,7	2,5	4,1	2,2	2,0	3,3	2,8	2,6	4,1	0,9	0,8	1,3	2,8	2,6	4,1
	sludge disposal	1,1	1,5	1,9	1,0	1,4	1,8	1,0	1,5	1,8	1,0	1,3	1,7	1,4	2,0	2,6
	other costs	1,1	1,2	1,5	1,1	1,2	1,5	1,2	1,3	1,7	1,1	1,2	1,5	1,5	1,6	2,1
	total	**10,0**	**11,9**	**17,2**	**9,8**	**11,8**	**17,0**	**11,1**	**13,1**	**18,8**	**9,8**	**12,1**	**17,0**	**13,6**	**16,4**	**23,3**
> 100000 pe in €/pe.a	materials/chemicals	1,3	1,4	1,4	1,3	1,4	1,4	1,3	1,4	1,4	1,3	1,4	1,4	1,3	1,4	1,4
	personnel costs	1,8	1,9	1,9	2,0	2,1	2,1	2,3	2,5	2,5	2,8	3,1	3,0	3,2	3,5	3,5
	external costs	0,7	0,7	1,1	0,7	0,7	1,2	0,6	0,7	1,1	0,6	0,6	1,0	0,9	1,0	1,6
	energy costs	2,3	2,4	2,3	1,8	1,9	1,8	2,3	2,4	2,3	0,7	0,8	0,7	2,3	2,4	2,3
	sludge disposal	1,1	1,5	1,8	1,0	1,4	1,7	1,0	1,5	1,7	1,0	1,4	1,6	1,5	2,1	2,4
	other costs	0,4	0,4	0,5	0,4	0,4	0,5	0,4	0,4	0,5	0,3	0,4	0,5	0,5	0,5	0,7
	total	**7,5**	**8,4**	**9,1**	**7,2**	**8,0**	**8,8**	**8,0**	**8,9**	**9,6**	**6,7**	**7,6**	**8,3**	**9,7**	**10,9**	**11,9**

operation costs C-plant		Slovakia			Slovenia			Turkey			Ukraine			Germany		
		25%	Med.	75%	25%	Med.	75%	25%	Med.	75%	25%	Med.	75%	25%	Med.	75%
10000 - 50000 pe in €/pe.a	materials/chemicals	0,9	1,2	1,8	0,9	1,2	1,8	0,9	1,2	1,8	0,9	1,2	1,8	0,9	1,2	1,8
	personnel costs	2,7	3,2	4,4	3,0	3,6	4,9	3,5	4,3	5,8	4,2	5,2	7,0	4,9	6,0	8,1
	external costs	0,6	0,9	1,6	0,6	1,0	1,7	0,5	0,9	1,5	0,5	0,8	1,4	0,8	1,3	2,2
	energy costs	2,3	2,1	3,4	1,8	1,7	2,7	2,3	2,1	3,4	0,7	0,7	1,1	2,3	2,2	3,5
	sludge disposal	0,9	1,3	1,6	0,8	1,2	1,5	0,8	1,2	1,5	0,8	1,1	1,4	1,2	1,7	2,1
	other costs	0,9	0,9	1,2	0,9	0,9	1,2	1,0	1,1	1,4	0,9	1,0	1,2	1,2	1,3	1,7
	total	**8,1**	**9,6**	**13,9**	**7,9**	**9,5**	**13,7**	**9,0**	**10,7**	**15,4**	**8,0**	**9,9**	**13,9**	**11,3**	**13,5**	**19,3**
> 100000 pe in €/pe.a	materials/chemicals	0,8	0,8	0,9	0,8	0,8	0,9	0,8	0,8	0,9	0,8	0,8	0,9	0,8	0,8	0,9
	personnel costs	1,5	1,6	1,6	1,7	1,8	1,8	2,0	2,2	2,1	2,4	2,6	2,6	2,8	3,1	3,0
	external costs	0,6	0,6	1,0	0,6	0,7	1,1	0,6	0,6	1,0	0,5	0,6	0,9	0,8	0,9	1,4
	energy costs	1,9	2,0	1,9	1,5	1,6	1,5	1,9	2,0	1,9	0,6	0,6	0,6	1,9	2,0	1,9
	sludge disposal	0,9	1,3	1,5	0,8	1,2	1,4	0,8	1,2	1,4	0,8	1,1	1,3	1,2	1,7	2,0
	other costs	0,3	0,3	0,4	0,3	0,3	0,4	0,3	0,4	0,4	0,3	0,3	0,4	0,4	0,4	0,5
	total	**6,0**	**6,7**	**7,3**	**5,7**	**6,4**	**7,1**	**6,4**	**7,2**	**7,7**	**5,4**	**6,1**	**6,7**	**7,9**	**8,9**	**9,7**

Questionnaire for new plants (similar questionnaires are developed for the categories “recent upgrade” and “upgrade soon”), Questionnaires are also translated into Russian language.

Start of operation	year	
Design capacity of the plant	population equivalent	1 population equivalent:
Current loading	population equivalent	60 g BSB5/inhabitant and day or 110 g CSB/inh.d 11 g N/inh.d 1,7 g P/inh.d
Average daily inflow	m^3/d	
Inflow concentration		
CSB/BSB$_5$	mg/l	
N_{tot}	mg/l	
NH_4	mg/l	
P_{tot}	mg/l	
PO_4	mg/l	
Actual effluent concentrations:		
CSB/BSB$_5$	mg/l	
N_{tot}	mg/l	
NH_4	mg/l	
P_{tot}	mg/l	
PO_4	mg/l	
Suspended solids	mg/l	
Removal efficiency for C:	%	
Removal efficiency for P (if applied)	%	
Removal efficiency for N (if applied)	%	

Description of plant configuration – treatment steps:

Investment costs: total	€
costs for construction (if available)	€
costs for machinery and electro-technical installations (if available)	€

Operation costs:

Average production of sewage sludge	t dry matter (dm) per year	
P-concentration in sludge	g/kg dm	
N-concentration in sludge	g/kg dm	
Kind of sludge dewatering		
Kind of sludge disposal		
Costs of sludge management		
Costs of dewatering	€/t dm	
Disposal charges	€/t dm	
Costs for combustion	€/t dm	
Charges for agricultural application	€/t dm	
Other management option (e.g. composting) and related costs	€/t dm	
consumption of electricity (kWh/a)	kWh/year	
Price of 1 kwh	€/kWh	
Management of biogas from sludge digestions		
Amount of biogas	m³/year	
energy efficiency of cogeneration unit	%	
Production of electricity	kWh/a	
Costs of cogeneration unit	€	
Number of employees of wwtp		
Average salary of wwtp staff	€/month	
Average salary in the construction sector	€/month	
Use and costs of chemicals		
Polymers	kg/a	€/kg
Precipitants (please specify which product)	kg/a	€/kg
Disinfection (please specify which product)	kg/a	€/kg
Reagens for laboratory (costs only)		€/kg

Levies for discharge

Other costs

Current emission standards: CSB/BSB_5, Ntot, (NH_4), Ptot (PO_4), SS (suspended solids)

(Near) Future emission standards: CSB/BSB_5, Ntot, (NH_4), Ptot (PO_4), SS (suspended solids)

6.2 Industry

6.2.1 Description of specific production processes and Best Available Techniques (BAT) for the Manufacture of Fertilisers

6.2.1.1 General remarks

Ammonia (NH_3), nitric acid (HNO_3), sulphuric acid (H_2SO_4) and phosphoric acid (H_3PO_4) belong to the quantitatively most important industrial chemicals and are mainly used for the production of fertilisers. 97% of the nitrogen fertilisers are derived from ammonia and 70% of phosphate fertilisers are derived from phosphoric acid.

Generally NPK, AN/CAN and phosphate fertilisers can be produced in the same line of equipment and abatement systems. Major consumers of energy for meeting various heating requirements and for driving different equipment are nitrogenous fertiliser plants. Often, bigger equipment is driven by steam, smaller by electrical motors. (EC 2006)

Common issues for best available techniques (BAT)

Large volume inorganic chemicals industry (LVIC) as a whole and fertiliser production as specific industrial branch are characterised by specific emission and consumption levels, which can be associated with specific techniques applied to the industrial production process. Where emissions and consumption levels are associated with best available techniques (BAT) are present this is to be understood as that those levels represent the environmental performance that could be anticipated as a result of application of BAT. These levels associated with BAT should not be understood as limit values for emissions or consumption. In some cases it may be technically possible to achieve better emission or consumption levels but due to costs involved or cross media effects they are not considered to be appropriate as BAT for the sector as a whole (EC 2006).

Each specific production of fertiliser manufacture industry has its specific best available techniques (BAT), which will be discussed within the specific topics. In general there are also common BAT for Large volume inorganic chemicals industry.

In general BAT is to:

- Carry out regular energy audits for the whole production site
- Monitor key performance parameters
- Establish mass balances (N, P_2O_5, steam, water, CO_2)
- Minimisation of energy losses
    - avoiding steam pressure reduction without using energy
    - adjusting the whole steam system in order to minimise generation of excess steam
    - Using the excess thermal energy
    - Using steam for generating only electrical power, if local factors prevent the use of excess thermal energy
- Improve the environmental performance of the production site
    - recycling or re-routing mass streams
    - efficiently equipment sharing

- increasing heat integration
- preheating of combustion air
- maintaining heat exchanger efficiency
- reducing waste water volumes and loads by recycling condensates, process and scrubbing waters
- apply advanced process control systems
- maintenance

BAT is also to apply environmental management system (EMS) that incorporate definitions of an environmental policy for the installations, planning and establishing the necessary procedures and to check and to review environmental performance (EC 2006).

6.2.1.2 Production of Ammonia

Ammonia is an intermediate product and required for the production of various straight nitrogen fertilizers. About 97% of the nitrogen fertilizers such as urea, ammonium-nitrate (AN) and calcium-ammonium-nitrate (CAN) are derived from ammonia. Ammonia is also used for the production of multi-nutrient fertilizers (NP- and NPK-fertilizer) (EC 2006; EFMA 1997; Umweltbundesamt 2002).

Most of the energy for fertiliser production is required for fixation of atmospheric nitrogen for ammonia manufacture.

Production process

Raw materials used for ammonia manufacture are hydrocarbon feed (natural gas (NH_4)), water and air. For the present and future time the steam/air reforming concepts based on natural gas or light hydrocarbons are considered to be the dominating group of BAT production processes.

BAT is to apply:

- conventional reforming (stoichiometric H/N ratio)
- reduced primary reforming and excess air secondary reforming (under-stoichiometric H/N ratio)
- heat exchange autothermal reforming

Production of ammonia using conventional reforming consists of the following processes:

Table 36: Description of processes of conventional reforming for production of ammonia

Process	Requirements
Desulphurication The catalysts used in the process are sensitive to sulphur compounds, sulphur is removed from gas feed.	- feed gas is pre-heated to 350 – 400°C (primary reformer convection section) - hydrogen for this reaction is recycled from synthesis section
Primary reforming The gas is mixed with process stream and heated before entering the primary reformer. $CH_4 + H_20 \leftrightarrow CO + 3H_2$ $CO + H_20 \leftrightarrow CO_2 + H_2$	- feed gas is pre-heated to 400-600°C (primary reformer convection section) - process stream to carbon molar ratio (S/C-ratio) should be around 3 for BAT - endothermic reation; temperature is raised to 780-830°C at reformer outlet

Secondary reforming 30-60% of feed gas is reformed in primary reformer. Internal combustion of part of gas with process air for heating. Process gas is mixed with process air in burner and then passed over secondary reformer. $2CH_4 + O_2 \leftrightarrow 2CO + 4H_2$	- process air is compressed and pre-heated to 500-600°C (primary reformer convection section) - process gas leaves secondary reformer with about 1000°C and has to be cooled to 350-400°C - residual methane content about 0.2-0.3%
Shift conversion Process gas from secondary reformer contains 12-15% CO. CO content is reduced in HTS to 3%. Gas from HTS is cooled and passed through LTS, where residual CO content is about 0.2-0.4%.	- high temperature shift (HTS) conversion (400°C) - low temperature shift (LTS) conversion (200-220°C)
CO_2 removal CO_2 is removed by absorption process using chemical or physical solvents. Heat released during cooling is used for regeneration of CO_2 scrubbing solution, driving absorption refrigeration and boiler feedwater preheat.	- gas is cooled, excess steam is condensed before entering CO_2 removal - Stripping of ammonia, methanol and other compounds from condensate
Methanation Small remaining amounts of CO and CO_2 must be removed by conversion to CH_4.	- Reaction at 300°C - Cooling and condensation downstream of methanator
Synthesis gas compression and ammonia synthesis $N_2 + 3H_2 \leftrightarrow 2NH_3$ 20-30% reacted per pass, ammonia is separated from recycle gas by condensation, reacted gas is substituted by fresh synthesis gas to maintain pressure. Purge gas containing inerts (Methane, argon) is taken out, washed to remove ammonia and used as fuel or for hydrogen recovery.	- For synthesis pressure of 100-250 bar and temperatures of 350-550°C are needed - Steam produced in ammonia plant is used to drive steam turbines for synthesis gas compression and for refrigeration compression (condensation of product ammonia) - Extensive heat exchange is required

Produced carbon dioxide within the process can be further used as feedstock in an urea plant or for multi-nutrient fertiliser production in the ODDA process (nitro-phosphate route).

Since the primary reformer has a low gas reforming efficiency (30-60%) moving some of the duty from the primary to the secondary reformer is practise in the steam reforming with excess air secondary reforming. Decreased heat supply, reduced size and costs for the primary reformer increased firing efficiency mean that increased firing in the secondary reformer is necessary to achieve the same degree of total reforming. The process air requirement is about 50% higher compared to the conventional process, this mean increased compression capacity and energy. Using cryogenic final purification removes almost all impurities from the make-up synthesis gas and is a significant improvement compared to the conventional purification by the methanator. Higher conversion per pass and reduced purge flows make this process more efficient.

Developments to better recycle the excess heat from reforming using the heat content of the secondary reformed gas in newly developed primary reformer resulted in the process of heat exchange autothermal reforming. Emissions to the air are reduced significantly, NO_x maybe reduced by 50% or more.

Developments of reforming processes are expected to.

- Lowering the steam to carbon ratio
- Shifting duty from primary to secondary reformer
- Improving final purification
- Improving synthesis loop efficiency
- Improving power energy system
- Low NO_x burner
- Non iron based ammonia synthesis catalyst

The high amount of surplus heat available from flue-gas of the primary reformer, the secondary reformer , shift conversion and the ammonia synthesis requires the design of an efficient overall steam system, in which high pressure steam is generated. A way to improve plant efficiency is to use gas turbine to drive air compressor and to use hot exhaust gases as preheated combustion air for the reformer. In this case energy losses encountered by steam condensation in the usually employed steam turbine are avoided. Also refrigeration compressor (needed for the condensation of ammonia) and the compressor for pressurising process air can be driven by steam turbine using steam generated in the plant mainly from waste heat. This allows an efficient integration into the energy system of the whole plant and improves the plant economics (EC 2006), (EFMA 2000a).

Key environmental parameters

Key environmental parameters are:

- Amount of feedstock (natural gas, water)
- Consumption of energy for heating the primary reformer
- Efficient heat recovery system
- Waste gas emissions from primary reformer (CO_2, NO_x, NH_3,SO_2, dust), from desorption of CO_2 (CH_4, CO, CO_2) and from removal of purge gases from synthesis loop (NH_3, CH_4)

Process waste water arises when process water is removed from synthesis gas by condensation. Recovery of ammonia from process waste water (e.g. by stripping) can be considered state-of-the-art technology (Umweltbundesamt 2002).

Energy consumption can be associated to ammonia production process as follows (EC 2006):

Product ammonia	71.9%
Unrecovered process heat	10.5%
Air compression turbine	7.8%
Syngas compressor turbine	5.7%
Flue-gas heat	2.4%
Refrigeration compressor turbine	1.8%
Miscellaneous	0.6%

BAT

Conventional reforming, reduced primary reforming and heat exchange autothermal reforming are considered to be BAT for ammonia production. Beside the different reforming processes further techniques are considered to be BAT, which in part do agree with expected developments in reforming processes:

- Techniques such as SNCR at the primary reformer to reduce NO_x emissions
- Low NO_x burners
- Ammonia removal from purge and flash gas
- Low temperature desulphurication for autothermal heat exchange reforming
- Low energy consumption levels due to
    - Extended preheating of hydrocarbon feed
    - Preheating of combustion air
    - Installation of second generation gas turbine
    - Modifications of furnace burners
    - Rearrangement of convection coils and addition of additional surface
    - Pre-reforming in combination with a suitable steam saving concept
- Improved CO_2 removal
- Use of smaller catalyst particles, catalyst allow low pressure ammonia synthesis, sulphur resistant catalyst
- Liquid nitrogen wash for final purification of synthesis gas
- Indirect cooling of ammonia synthesis reactor
- Hydrogen recovery from purge gas
- Implementation of advanced process control system
- Remove NH_3 from process condensates e.g. by stripping

This list of BAT measures will not be discussed in detail. These measures are more or less to reduce energy consumption, to more efficiently use feed gas and steam and to use more efficiently exhaust steam and heat.

In terms of process waste water emissions the last measure is of importance to reduce emissions of ammonia and methanol. Using process steam for stripping of ammonia and methanol emission reductions of up to 95% can be achieved. Emission levels of about 1 kg/m^3 of each ammonia and methanol in process waste water (about $1m^3/t$ NH_3 condensate is produced, production capacity 1500 t NH_3/d) can be reduced to 0.02 … 0.1 kg/ t NH_3.

Specific waste water emissions

Table 37: Waste water emissions arising from the production of ammonia, from (Umweltbundesamt 2002)

Pollutant	Waste water emission levels
Process water (m^3/h)	25-49
NH_4-N (kg/t NH_3)*	0.6-0.7
CSB (kg/t NH_3)*	0.8-1.0

*…before installation of stripping unit

6.2.1.3 Production of ammonium nitrate (AN) and calcium ammonium nitrate (CAN)

Ammonium nitrate (AN) is used extensively as a nitrogenous fertilizer. It is made by the reaction between gaseous ammonia and aqueous nitric acid or by conversion of calcium nitrate tetra hydrate (CNTH), which is obtained as a by-product of the ODDA process. The resultant AN can be:

- Stored as solution and used in down-stream (other plants)
- Formed into solid ammonium nitrate by prilling or granulation
- Mixed with a solid filler (most common filler is calcium carbonate to make “calcium ammonium nitrate” (CAN)) and then prilled or granulated

CAN is the most applied fertiliser product in Western Europe. If the production plant is to qualify for BAT, the product must conform to specifications of the Fertilizer Regulations in the European Union (labelled EC Fertilizer) (EFMA 2000b).

Production process

The production process comprises of three main unit operations:

- Neutralisation
- Evaporation
- Solidification (Prilling and Granulation)

The **neutralisation** of nitric acid with ammonia gas produces ammonium nitrate solution, stream and heat (highly exothermic reaction). The heat produced is often used to generate stream. Nitric acid is commonly preheated, this can be performed according to BAT by using steam or hot condensates from ammonium nitrate process. Neutralisation can be performed in a single stage or two stages. A two stage neutraliser operates with low pH in the first stage and with neutral pH in the second stage.

Neutralisation at an elevated pressure will produce steam with higher temperatures and ammonium nitrate with higher concentration. Such steam could be used in down-stream processes for evaporation and drying. BAT requirements should include a careful design of the neutralisers to reduce steam containing ammonia and ammonium nitrate, exclusion of impurities, recycling of fines and oversizes to the process and recycling of ammonium nitrate solution (e.g. from contaminated steam condensate).

The steam leaving the neutraliser can be purified, or it can be condensed and then purified. The steam can be used in the evaporator, to preheat and evaporate ammonia or to preheat the nitric acid. For steam purification wire mesh demister, wave plate or fibre pad separators, venturi scrubbers, packed columns or irrigated sieve plates can be used. Ammonium nitrate emissions from neutralisers are very difficult to remove because of fine particles. A combination of droplet separators and scrubbers is useful. For the use of Scrubbers (Packed columns, venturi scrubbers, irrigated sieve plates) BAT would require the addition of acids (nitric acid) to neutralise any free ammonia and to optimise the removal.

Condensate treatment must be considered if the condensate does not meet BAT requirements and can be achieved by stripping (with air or steam with addition of alkali to liberate ionised ammonia), distillation or membrane separation processes.

Evaporation is normally required to remove the majority of the water content from ammonium nitrate solution and is always performed using steam from ammonium nitrate process or from a steam raising facility on the site. Decomposition of ammonium nitrate by evaporation should be avoided using saturated steam at an appropriate temperature. The steam which is boiled off is contaminated with ammonia and droplets of ammonium nitrate, which have to be purified by droplet separators or scrubbers or have to be condensed and purified with condensates from neutralisation.

Prillling refers to the formation of granules by solidification of droplets of fertilizer material. In prilling towers the ammonium nitrate solution is sprayed into the top of the tower forming droplets, which are cooled and solidified falling through the tower. For the production of **CAN**, calcium carbonate or dolomite limestone is added prior to the formation of droplets. Atmospheric effluents from prilling result in losses of ammonia and ammonium nitrate. Ammonia can be removed by neutralisation in wet scrubbers. Ammonium nitrate fumes are cleaned using irrigated glass fibre filters (not applicable for CAN).

Granulation refers to techniques using agglomeration, accretion or crushing producing a larger granule compared to prilling techniques. Granulation will be performed using rotating pans and drums, fluidised beds or other equipment. Due to larger particle size drying of granules can be required. Atmospheric effluents are comparable to prilling, but the quantity of emissions to the air is much smaller and abatement equipment much cheaper and easier to install. Emissions to the air contain coarser particles and can therefore be treated using scrubbers. Wet scrubber solution will be recycled to the process if possible (adverse effects on granulation).

The produced product from both prilling and granulation has to be cooled in rotary or fluid bed coolers with air cleaned by high efficiency cyclones, bag filters or wet scrubbers.

Conditioning before storage is necessary for solid AN and CAN because of cacking. These additives may also prevent dust formation and moisture pick-up during storage (EC 2006), (EFMA 2000b), (Umweltbundesamt 2002).

Key environmental parameters

Main emissions from AN and CAN production arise from

- process water from condensing the steam leaving the neutralisation reactor
- exhaust vapours from evaporation of AN solution
- off-gases from prilling, granulation and drying

Purified process condensate can be used for waste gas scrubbing or can partly be recycled in other plants e.g. as process water for nitric acid production or for scrubbing water in a nitrophosphate plant. Scrubbing waters from waste gas treatment of granulation and drying can be recycled into the production process. (Umweltbundesamt 2002).

BAT

BAT for AN / CAN production is to:

- optimise neutralisation/evaporation stage by:
    - heat of the reaction to preheat the HNO_3 and/or vaporise NH_3
    - operating neutralisation at elevated pressure and exporting steam
    - using the generated steam for evaporation of AN solution
    - recovering residual heat for chilling process water
    - using the generated steam for the treatment of process condensates
    - using the heat of the reaction for additional water evaporation
- effectively and reliably control pH, flow and temperature

- improve environmental performance of finishing section
- reduce dust emissions from dolomite grinding
- recycle process water and to treat remaining waste water in biological treatment plant (EC 2006)

Specific waste water emissions

Table 38: Waste water emissions arising from the production of AN pressure neutralisation, from (Umweltbundesamt 2002)

Pollutant	Emission levels
Waste water volume	6 m^3/h (0.24 m^3/t)
Total N (NH_3-N + NO_3-N)	6 kg/d (0.026 kg/t N*)

*…calculated based on daily production capacity (t AN/d) and N content in AN of 34%

6.2.1.4 *Production of Multi-Nutrient (MN) Fertiliser by nitrophosphate route (ODDA process)*

Multi-nutrient fertilizer based on nitrate mineral compounds are “NP” or “NPK” fertiliser. These products contain nitrogen in ureic, ammoniacal (NH_4) and nitrate (NO_3) form, phosphorus expressed as P_2O_5 and normally also potassium as K_2O. The nutrient content (N+ P_2O_5+ K_2O) of these fertilizers will be usually between 30-60%.

These compound fertilisers can be produced in two production routes:

- The nitric acid route or **nitrophosphate route**
- The sulphuric acid route or **mixed acid route**

Although the nitrophosphate route requires higher investment and integration with other fertiliser production, it offers the option to increase the P content in the product without using phosphoric acid.

In the nitrophospate process all nutrients are totally used in the production of nitrate containing fertilisers, but this process is restrictive in the sense that only nitrate-containing fertilisers can be produced. This needs a high integration of different plants (e.g. of ammonia plant) and corresponding investments. (EC 2006), (EFMA 2000c)

Production process

Both the nitrophosphate route as well as the mixed acid route using phosphate rock as raw material, which is digested either with nitric acid (nitrophosphate route) or with a combination of nitric, sulphuric and/or phosphoric acid (mixed acid route). Because of the required starting materials and the co-products, the nitrophosphate route (ODDA process) is usually integrated with ammonia, HNO_3 and CAN production.

After phosphate rock digestion (T = 60-70°C) the solution is cooled (T = 0-20°C) to separate out most of the calcium ions as calcium nitrate tetrahydrate crystals (CNTH). After filtration of calcium nitrate crystals the resulting NP solution (containing the remaining calcium nitrate, H_3PO_4 and HNO_3, called nitrophosphoric acid) is neutralised using ammonia, mixed with potassium/magnesium salts, sulphate and/or micro-nutrients and converted in a rotary granulation drum, fluidised bed, prilling tower or pug mill to obtain solid compound fertiliser.

The by-product calcium nitrate crystals are dissolved with ammonium nitrate and treated with ammonium carbonate. By filtration calcium carbonate crystals are removed from the solution and used for the production of granular CAN or, after purification, marketed as CN fertiliser. The remaining ammonium nitrate solution is concentrated and also used to produce CAN or NPK fertiliser. Remaining calcium nitrate solution can be neutralised and evaporated to obtain solid fertiliser.

The main difference to the process based on sulphuric acid is that no gypsum is formed in this process (EC 2006), (EFMA 2000c).

Key environmental parameters

Phosphate rock digestion is highly exothermic and leads to NO_x and fluorides emissions, which are collected together with off-gases from (sand) washing and crystallisation section and treated in scrubbing units before discharge to the atmosphere. Off-gases from CNTH conversion are treated in scrubbing columns and scrubbing liquid is recycled. Liquid effluents are generated by condensation of evaporation gases (AN evaporation section) and are recycled, used for cleaning purposes or treated and discharged.

Main effluent components of emissions into water from nitrophosphate process (without consideration of CAN or NPK production) are ammonia, nitrate, fluoride and phosphate. Phosphate emissions originate from sand washing and can be reduced via recycling the liquor (from 0.4 to 0.02 kg P_2O_5 / t P_2O_5). Main sources of nitrate and fluoride are scrubbing liquids of rock digestion and sand washing and can be reduced by recycling of the NO_x scrubbing liquors (from 1.2 to 0.6 kg N/t P_2O_5 and from 0.7 to 0.02 kg F/t P_2O_5). Ammonia emissions occur when not all condensates from AN evaporation or the neutralisation of the nitrophosphoric acid can be recycled.

NPK production from neutralisation of nitrophosphoric acid with ammonia produces off-gases. Treatment is realised using condensing or scrubbing systems. Recycling of the condensates and scrubbing liquids is dependent on the water balance of the grade which is produced.

Ventilation gases from neutralisation and evaporation of remaining CNTH are scrubbed with water. Process steam containing ammonia is scrubbed with condensate and compressed for use in evaporators. Parts of the condensates are discharged into water, the remainder is returned to the process. For a 100 $t*h^{-1}$ CN plant scrubbing discharges are <0.3 $kg*h^{-1}$ and condensate discharges are around 30 $kg*h^{-1}$. Ventilation gases from granulation and drying part are scrubbed with water and process condensate. Scrubbing liquid and condensate containing CNTH is returned to neutralisation section.

The following measures allow a considerable **reduction of waste water emissions** for MN fertiliser production by nitrophosphate route:

- Recycling of waste water from waste gas scrubbing at the phosphate rock digestion
- Recycling of washing liquor for sand washing
- Avoidance of the use of co-condensation
- Recycling of scrubbing liquor from waste gas scrubbing of the ammoniation into the production process
- Combined waste gas scrubbing of neutralisation/evaporation and the granulation units

The amount of liquid effluent which has to be removed from the production process, mainly results from the amount of water which is introduced into the process with nitric acid or via the recycling of washing liquors or scrubbing liquors into the production process. Large fractions of liquids are removed via production process via moisture of the off-gases or via combined scrubbing. Waste water which cannot be avoided is discharged after adequate treatment (EFMA 2000c), (Umweltbundesamt 2002).

BAT

BAT for the production of NPK fertiliser is to:

- Reduce dust emission from rock grinding (application of fabric filters, ceramic filters)
- Prevent dispersion of phosphate rock dust by using covered conveyor belts, indoor storage, and frequently cleaning /sweeping the plant grounds and the quay
- Improve the environmental performance of the finishing section by
    - Applying plate bank product cooling
    - Recycling of warm air
    - Selecting proper size of screens and mills
    - Apply surge hoppers for granulation recycle control
    - Apply online product size distribution measurement for granulation recycle control
- Minimise NO_x load in exhaust gases from phosphate rock digestion by
    - Accurate temperature control
    - Proper rock/acid ratio
    - Phosphate rock selection
    - Or by controlling other relevant process parameter
- Reduce emissions to air from phosphate rock digestion, and washing and CNTH filtration by applying multistage scrubbing
- Reduce emissions to air from neutralisation, granulation, drying, coating and cooling by
    - Dust removal, such as cyclones and/or fabric filters
    - Wet scrubbing
- Minimise waste water volumes by recycling washing and rinsing waters and scrubbing liquors into the process, e.g. by using residual heat for waste water evaporation
- Treat the remaining waste water volumes adequately e.g. by biological treatment including nitrification/denitrification and precipitation of phosphorus compounds (EC 2006)

Specific waste water emissions

Table 39: Waste water emissions arising from the production of MN fertilisers (including CNTH conversion) by nitrophosphate route, from (Umweltbundesamt 2002)

Pollutant	**Waste water emission levels**	
Process water (m^3/d)	3457	
Filterable substances	215 kg/d	1.47 kg/t P*
PO_4	77 kg/d	0.53 kg/t P*
NH_4-N	100 kg/d	0.68 kg/t P*

NO_3-N	124 kg/d	0.85 kg/t P*
NO_2-N	2 kg/d	0.01 kg/t P*
Fluoride	43 kg/d	0.29 kg/t P*

*…calculated based on daily production capacity (t MN/d) and P_2O_5 content in MN fertiliser of 28%

6.2.1.5 Production of urea and urea ammonium nitrate (UAN)

Urea has become the most used solid nitrogen fertiliser in the world, mainly because of its use for flooded rice. Urea is also used in melamine manufacture, for various urea/formaldehyde resins/adhesives and as a cattle feed supplement (inexpensive N source). It is also applied in $DeNO_x$ treatment of waste gases (SCR and SCNR) (EC 2006).

Production process

The synthesis of urea is achieved by the reaction of ammonia and carbon dioxide at high pressure forming ammonium carbamate, which is then dehydrated by applying heat, forming urea and water.

Both reactions take place in the liquid phase of the same reactor, typical production conditions are 140-250 bar (pressure), 180-210°C (temperature) and 2.8:1 – 4:1 (NH_3/CO_2 ratio).

The first reaction (formation of carbamate) is fast and exothermic and essentially goes to completion under industrial reaction conditions used. The second reaction is slower and endothermic and does not go to completion. The conversion is usually in order of 50 – 80% (on CO_2 basis). The conversion increases with increasing temperature and NH_3/CO_2 ratio and decreases with increasing H_20/CO_2 ratio.

Several side reactions, as the hydrolysis of urea (reverse reaction of urea formation), formation of biuret (might cause crop damage) and formation of isocyanic acids have to be limited or minimised.

Efficient separation of urea from other reaction components, recovery of excess NH3 and decomposition of residual carbamate to NH_3 and CO_2 for recycling into the process is intended in terms of economic conversion rates. This is realised by stripping (still at high pressure) and subsequent depressurisation/heating of the urea solution or combination of both.

The urea solution from synthesis/recycling stages of the processes is concentrated via evaporation or crystallisation to a urea melt for conversion to a solid prilled or granular product.

UAN (urea ammonium nitrate) is produced by mixing concentrated urea and ammonium nitrate solutions either in continuous or batch processes (EC 2006), (EFMA 2000d).

Key environmental parameters

Main sources of Urea, NH_3 and CO2 in process water are:

- Evaporator condensate
- Off-gases from the recovery/recirculation stage absorbed in process water
- Off-gases from synthesis section absorbed in process water
- Flush and purge water from pumps

- Liquid drains from the recovery section

(EFMA 2000d)

Process water BAT treatment systems

For recovery of NH3 and CO2 from process water different treatment systems are available. Using desorption-hydrolysis-systems or distillation-hydrolysis-systems NH_3 and CO_2 is eliminated from process water via stripping/distillation and will be recycled to the production process. Hydrolysis sections are used for decomposition of remaining urea and for subsequent recovery of NH_3 and CO_2. With both systems concentrations of 5 mg/l NH_3 and 1 mg/l urea can be expected. Using stripping-hydrolysis-systems free NH_3 and urea concentrations of 3-5 mg/l each are expected.

Existing plants show varying values for emissions into water of 20-230 mg/l NH_3 (0.01-0.61 kg NH_3/t of product) and 20-320 mg/l urea (0.01-0.84 kg urea/ t of product). (EFMA 2000d)

BAT

BAT for Urea /UAN production is to:

- Improve environmental performance of finishing section by one or the combination of:
    - Application of plate bank product cooling
    - Redirecting urea fines to the concentrated urea solution
    - Select proper size of screens and mills
    - Application of surge hoppers for granulation recycle control
    - Application of product size distribution measurement and control
- Optimise total energy consumption by applying:
    - Continue stripping technology for existing stripping installations
    - Applying total recycling stripping processes for new installations
    - Upgrading stripping technology for existing conventional total recycling installations (only in case of substantial urea plant capacity increase)
    - Increase heat integration of stripping plants
    - Applying combined condensation and reaction technology
- Treatment of all exhaust gases from wet sections by scrubbing and to recycle the ammonia solutions to the process (with consideration of lower explosion limit)
- Reduction of ammonia and dust emissions from prilling and granulation and to achieve ammonia emission levels of 3-35 mg /Nm^3 (dust emission levels of 15-55 mg/Nm^3) by
    - Scrubbing and re-use of scrubbing liquids on-site (preferably by acidic scrubbing; without re-use with water scrubbing) or by
    - Optimisation of operation conditions of the prill tower
- Treatment of process water, where process water is not re-used, by desorption and hydrolysation or by biological waste water treatment (in existing plants, where desired emission levels can not be achieved)
- Monitoring of key performance parameters

Desired emission levels after treatment of process waste water:

New plants: 1 mg/l NH_3 1 mg/l urea

Existing plants: <10 mg/l NH_3 <5 mg/l urea

(EC 2006)

Specific waste water emissions

Table 40: Waste water emissions arising from the production of Urea/UAN, from (Umweltbundesamt 2002)

Pollutant	Waste water emission levels	
NH_4-N	109 kg/d	0.22 kg/t N
TKN	270 kg/d	0.55 kg/t N
COD	23.3 kg/d	0.05 kg/t N

6.2.1.6 Production of superphosphates

Superphosphates are defined by the percentage of phosphorus as P_2O_5 and are used as straight fertilisers and also as a feedstock for multi-nutrient (MN) fertiliser production. Single superphosphate (SSP) and triple superphosphate (TSP) are mainly used for the production of NPK or PK fertilisers. (EC 2006), (EFMA 2000e)

Production process

SSP and TSP are manufactured treating phosphate rock with either sulphuric acid (SSP) or phosphoric acid (TSP). The insoluble phosphate rock is converted into soluble phosphate and calcium sulphate (gypsum). After 30-40 minutes about 96% of the superphosphate is produced, but the reaction continues for several days as long as free acid reacts with excessive phosphate rock.

The superphosphate is crushed and afterwards fed to a granulation line (direct granulation) or to storage (pile) for “curing” from one to up to six weeks in order to complete the reaction. The superphosphate can be granulated or sold without further processing from storage facility. Direct granulation has some advantages in comparison to prior storage (curing); production costs are usually lower and the granules are denser and stronger. Some disadvantages of direct granulation are the need to use reactive phosphate rock and the possibility of greater losses of soluble P_2O_5 due to incomplete reactions.

Beside SSP and TSP also partially acidulated phosphate rock (PAPR) can be produced in superphosphate plants using a lower proportion of H_2SO_4 or H_3PO_4 to phosphate rock.

Waste gases from SSP/TSP production containing dust and considerable amounts of HF and SiF_4 are treated by wet scrubbing (EC 2006), (Umweltbundesamt 2002).

Key environmental parameters

Dust emissions arise from grinding of the phosphate rock and are treated by fabric filters.

Emissions of dust, HF and SiF_4 arise from the digestion of phosphate rock. The production of TSP evolves less SIF_4 than the production of SSP. Off-gases are supplied to multi-stage scrubber, in which the SIF_4 reacts with water forming fluosilicic acid and SiO_2. The scrubbing liquid is dilute, circulating fluosilicic acid. With regard to HF emissions removal efficiencies of

>99% are achievable.

Scrubbing liquor is contaminated with phosphates, fluorine compounds, sulphates and heavy metals. In particular the discharge of highly toxic fluosilicic acid (which arises in considerable amounts) is of major environmental concern.

Recycling of scrubbing solution is limited by opportunities for direct use of fluosilicic acids. A possible solution would be in the production of a mixture of silica and precipitated calcium fluoride, which can successfully be sold to the cement industry. Currently, in a reference plant waste water is neutralised and discharged (Umweltbundesamt 2002).

BAT

BAT for the production of superphosphates is to:

- Reduce dust emissions from rock grinding by e.g. fabric filters or ceramic filters
- Prevent dispersion of phosphate rock dust by using covered conveyor belts, indoor storage, and frequently cleaning /sweeping the plant grounds and the quay
- Improve the environmental performance of the finishing section by
    - Applying plate bank product cooling
    - Recycling of warm air
    - Selecting proper size of screens and mills
    - Apply surge hoppers for granulation recycle control
    - Apply online product size distribution measurement for granulation recycle control
- Reduce fluoride emissions by application of scrubbers with suitable scrubbing liquids
- Reduce waste water volumes by recycling of scrubbing liquids, where, beside manufacture of SSP and TSP, acidulated phosphate rock (PAPR) is also produced
- For SSP/TSP production and multipurpose production to reduce the emissions to the air from neutralisation, granulation, drying, coating, cooling by
    - Applying cyclones and/or fabric filters
    - Wet scrubbers

(EC 2006)

Specific waste water emissions

Table 41: Waste water emissions arising from the production of P fertilisers (selected parameters), from (Umweltbundesamt 2002)

Pollutant	Waste water emission levels
Waste water volume (m^3/h)	5-10
Filterable substances (kg/t P_2O_5)	0.36
Total P (kg/t P_2O_5)	0.59
Ammonium as N (kg/t P_2O_5)	1.7
Fluorine compounds as F(kg/t P_2O_5)	1.17
CSB (kg/t P_2O_5)	0.6

6.2.1.7 Production of Multi-nutrient (MN) Fertiliser by mixed acid route

Multi-nutrient fertilisers can be produced in two production routes:

- The nitric acid route or **nitrophosphate route**
- The sulphuric acid route or **mixed acid route**

(EC 2006), (EFMA 2000e)

Production process

There are several processes for the production of MN fertiliser using the mixed acid route. Starting materials might be:

- Phosphoric acid
- Single superphosphate (SSP) or triple superphosphate (TSP)
- Nitrophosphoric acid (digestion of phosphate rock with HNO_3)

Solid starting materials (SSP, TSP, K-salts) are dosed into a granulator. For the production of NPK fertilizer ammonia, phosphoric acid (e.g. granulation with pipe reactor system) or sulphuric acid (e.g. drum granulation with ammoniation) is dosed to the granulator. For the production of PK fertilisers, SSP or TSP is granulated together with K-salts in the granulator. Scrubbing solution from off-gas treatment by wet scrubbing is recycled into the production process. In the granulator the mixture of raw materials and recycles is adjusted for agglomeration by injecting steam and water. The resulting product is dried and cooled.

Phosphate rock digestion using HNO_3 results in a first step in solution of phosphoric acid and calcium nitrate. Other raw materials such as phosphoric, sulphuric and nitric acids or AN solutions are added after digestion. The mixed acid is ammoniated with gaseous ammonia and after neutralisation other components such as ammonium phosphates, superphosphates ammonium sulphates and compounds containing potassium and magnesium are added. Afterwards granulation, drying , cooling and coating is performed.

Off-gases from phosphate rock digestion are scrubbed to recover NO_x and F compounds. Off-gases from ammoniation are treated with multi-stage scrubbing system using a mixture of NHO_3 and/or H_2SO_4. Drying off-gases are scrubbed with recycling of separated solids to the production process (EC 2006), (EFMA 2000e), (Umweltbundesamt 2002).

Key environmental parameters

The recycling of waste water is easier for grades of low nitrogen content than for grades with high nitrogen contents. In principle, the aim should be to recycle all the waste liquids from the production of all grades.

The main ammonia emissions originate from ammoniation reactors and are dependent on pH, temperature and slurry viscosity.

Nitrogen oxide emissions are mainly NO and NO_2, with some nitric acid. The main source of NO_x emissions is phosphate rock digestion, emissions are affected by the nature of phosphate rock and can be reduced by cooling the reactor or by addition of urea solution to the reactor.

Fluorine emissions originate also from phosphate rock digestion and go mainly through the production process into the fertiliser. Only a minor part is released into the gaseous phase.

Additionally, ammonium nitrate, ammonium fluoride and ammonium chloride are released as aerosols in the reaction between ammonia and acidic components as well as by sublimation of the boiling reaction mixture.

All solid and liquid wastes are aimed to be recycled but especially in existing plants this is not fully possible due to the applied design of scrubbing equipment and condensate system and have to be judged against the recipient receiving the waste liquid (EFMA 2000e), (Umweltbundesamt 2002).

BAT

See MN production by nitrophosphate route – chapter 4.3.