Deliverable 8.1. RECOCA. Structure of BALTCOST Drainage Basin scale abatement cost minimisation model for nutrient reductions in Baltic Sea regions

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Relevance to the Bonus progress indicators

- Publication dealing with cost-efficiency analysis of different environmental developments and options
- Publication addressing development/improvement of the prediction tools, including socioeconomics
- Publication proposing a way of improving the effectiveness and adaptive ability of the regulatory and mitigation/remedial measures.

Annotation :
This document describes the structure of the cost-minimisation model BALTCOST which is an evolutionary development of a mathematical programming model to identify the most cost-effective configuration of abatement measures to deliver e.g. HELCOM BSAP nutrient load reduction targets for each of the Baltic Sea regions. Attempting to fulfil both nitrogen and phosphorus load reduction targets in specific sea regions, BALTCOST identifies to what extent different measures should be applied - and in which locations – in order to deliver the specified load reduction targets at the lowest possible cost. The model includes abatement measures in arable and livestock farming, wetland restoration and waste water treatment.

Content

1. Objectives of the report

The objective of workpackage 8 in RECOCA is to i) improve the existing COST model with respect to measure coverage and data quality, ii) analyse cost-effective solutions at a Baltic-wide scale and iii) analyse the informational situation for international and regional decision-makers.

Work package 8 consists of 3 deliverables:

Deliverable 8.1.: Part 8.1.1.:Improvement of the BALTCOST model & Part 8.1.2. Implementation in NEST.

Deliverable 8.2.: The implications which uncertainty regarding nutrient transport carries for the cost-effective solutions.

Deliverable 8.3. Report on the implications of the informational situation for central and regional decision makers with regard to policy choice and strategic interaction.

The objective of this deliverable report is to document the work undertaken in work package 8.1.1.

The following tasks was planned to be undertaken as part of the work in the work package:

Task 8.1 Baseline scenario establishment (same as for WP 7): The baseline scenario year is 2005, and all data are either from 2005 or adjusted to the level of 2005.

Task 8.2 Improvement of cost functions and extended measure coverage, in particular for the new EU-member states and Russia: all cost data as well as the data for capacities and effects are revised, so that the new COST model BALTCOST is a fundamentally new model, building on the data retrieved in the other parts of RECOCA. New and updated cost data are also implemented, as described in the annexes to this report.

Task 8.3 Integration of catchment model (same as WP 7): The BALTCOST model has been integrated with the catchment models, the particular implementations used to achieve this are explained for each of the abatement measures in the annexes to this report.

Task 8.4 Integration with the marine model, including the possibility to investigate cost-effective solutions to improvements in different ecological indicators. The marine model is integrated as sea region divisions and sea region specific targets for nutrient loads. The transport matrix in the former SANBALT model, which was previously integrated in the COST model, has been withdrawn from the BALTCOST model and the BALTCOST model now minimises costs for delivering the required load reduction targets for each sea region separately, rather than for the Baltic Sea as a whole. The reason for this is that the transport of nutrients between sea regions is already taken into account in setting the targets of HELCOM BSAP. Further work integrating dynamic flows of nutrient between the sea regions, as well as the dynamics of nutrient stocks, will be a potential improvement of the model but is outside the scope of this project as further cooperation with marine modellers would be required.

Task 8.5 Analysis of cost-effective scenarios at the Baltic-wide level under certainty and uncertainty: Sensitivity analysis of the implications of nutrient retentions within the drainage basins is conducted, using two sets of retention coefficients produced in the catchment modelling by MESAW and the HL method. The BALTCOST model is run with these two sets of retentions, as well as without nutrient retentions, and the implications which these different retentions carry for nutrient loadings into the sea and for total abatement costs are discussed in deliverable 8.2.

Task 8.6 Analysis of the differences in informational situation to international and regional decision makers and the implication it has with regard to policy choice and the incentives for strategic decision-making. This task is analysed in deliverable 8.3.

2. Background

The discharges of nitrogen and phosphorous from the countries around the Baltic Sea cause serious water quality problems such as eutrophication and oxygen deficits. Several plans and directives have been instituted to improve water quality in inland and marine waters (The Water Framework Directive, WFD -The European Parliament and the council of the European union 2000, and the Marine Strategy Framework Directive –MSDF, The European Parliament and the council of the European union, 2008, and the Baltic Sea Action Plan- BSAP, HELCOM 2007). The BSAP is specifically intended to improve the water quality in the Baltic Sea. One target of the BSAP is to reduce the eutrophication of the sea-regions by setting targets for reducing both nitrogen and phosphorus loads to the sea regions..

To be able to assess how the targets set in different plans, e.g. the BSAP, can be achieved most cost-effectively a cost-minimisation model BALTCOST has been evolutionary developed. The model has been developed in Work package 7 and 8 of RECOCA as well as part of the Baltic Nest Institute, Denmark, taking departure in a former cost-minimisation model for the Baltic sea area developed by Schou et al. (2007) as part of the MARE project. The new model BALTCOST uses new cost data for each of the measures implemented, and compared to former models the BALTCOST model is based on a much more comprehensive and regionalised biophysical data set, using the comprehensive RECOCA databases including consistent data on nutrient applications, retentions, land use patterns and crop allocation, livestock, waste water treatment etc. In addition BALTCOST version 8.0 is built on the most recent cost-data available.. The BALTCOST model is currently being implementaed in the NEST-system.

This report describes the BALTCOST model structure and documents all the abatement measures featured in the model. The cost data and the physical data used for modelling these measures are enclosed as annexes to this report

3. BALTCOST

The BALTCOST model identifies the minimum cost combination of nitrogen (N) and phosphorus (P) abatement measures to deliver specified, separate nutrient load reduction targets for 7 separate Baltic Sea regions, see Table 1 and Figure 1.

Table 1: The 7 Baltic Sea Regions used in BALTCOST

Sea Region ID	Sea Region Name
BB	Bothnian Bay
BP	Baltic Proper
BS	Bothnian Sea
DS	Danish Straits
GF	Gulf of Finland
GR	Gulf of Riga
KT	Kattegat

Abatement measures are implemented in 9 Baltic Sea littoral countries (Table 2 & Figure 1), divided into 22 drainage basins (see Table 3 and Figure 1).

Table 2: The 9 Baltic littoral countries used in BALTCOST

Country ID	Country Name
DE	Germany
DK	Denmark
EE	Estonia
FI	Finland
LT	Lithuania
LV	Latvia
PL	Poland
RU	Russia
SE	Sweden

Figure 1: The Baltic Sea including country boundaries, sea regions & main drainage basins

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Table 3: The 22 main Drainage Basins modelled with BALTCOST

Drainage Basin ID	Drainage Basin Name
DE-BP	Germany into Baltic Proper
DE-DS	Germany into Danish Straits
DK-BP	Denmark into Baltic Proper
DK-DS	Denmark into Danish Straits
DK-KT	Denmark into Kattegat
EE-BP	Estonia into Baltic Proper
EE-GF	Estonia into Gulf of Finland
EE-GR	Estonia into Gulf of Riga
FI-BB	Finland into Bothnian Bay
FI-BS	Finland into Bothnian Sea
FI-GF	Finland into Gulf of Finland
LT-BP	Lithuania into Baltic Proper
LV-BP	Latvia into Baltic Proper
LV-GR	Latvia into Gulf of Riga
PL-BP	Poland into Baltic Proper
RU-BP	Russia into Baltic Proper
RU-GF	Russia into Gulf of Finland
SE-BB	Sweden into Bothnian Bay
SE-BP	Sweden into Baltic Proper
SE-BS	Sweden into Bothnian Sea
SE-DS	Sweden into Danish Straits
SE-KT	Sweden into Kattegat

The 22 main drainage basins are further divided into 117 watersheds, and each of the drainage basins comprises between 1 and 16 separate watersheds each. The watersheds are listed in Table 4, Annex 1.

4. The optimisation problem in BALTCOST: optimisation per Baltic Sea region

The BALTCOST model receives separate load reduction targets for N and P for the 7 Baltic Sea regions. BALTCOST seeks to identify the minimum cost combination of N and P abatement measures across those drainage basins which drain into a particular sea region, subject to satisfying the reduction targets for *both* N and P loads into that particular sea region. Abatement cost minimisation is carried out separately for each Baltic Sea region in turn to produce a cost efficient solution for the Baltic as a whole, given the N and P load reduction targets assigned to the separate Baltic Sea regions.

The current version of BALTCOST (Version 8.0) does not include a transport matrix of nutrient transports between sea region. The results presented here thus do *not* account for transport of nutrients between sea regions.

The cost minimisation problem solved by BALTCOST is:

$$\min \sum_{DB=1}^{DB=22} \sum_{m=1}^{m=5} C_{DBm}\left(a_{DBm}\right)$$

Subject to:

$$\sum_{DB=1}^{D\mathrm{B\ into\ sea\ region}} \sum_{\mathrm{m}=1}^{\mathrm{m}=5} g_{DB}^{N}\left(a_{DBm}\right) \geq T_{searegion\_N}$$

and

$$\sum_{DB=1}^{D\mathrm{B\ into\ sea\ region}} \sum_{\mathrm{m}=1}^{\mathrm{m}=5} g_{DB}^{P}\left(a_{DBm}\right) \geq T_{searegion\_P}\ *$$

and

$$a_{DBm\_\max} \geq a_{DBm} \geq 0$$

Where:

m indexes abatement measures

DB indexes drainage basins

searegion denotes separate sea regions

N indicates nitrogen

P indicates phosphorus

a_{DBm} reports the level of implementation of measure *m* in drainage basin *DB*

$C_{DBm}\left(a_{DBm}\right)$ reports the cost of implementing measure *m* at level a_{DBm} in drainage basin *DB*

$T_{searegion\_N}$ is the nitrogen load reduction target allocated to a particular sea region

$T_{searegion\_P}$ is the phosphorus load reduction target allocated to a particular sea region

$g_{DB}^{N}(\ )$ is the effective transfer coefficient for nitrogen from drainage basin *DB* to its river mouth discharging into the relevant sea region.

$g_{DB}^{P}(\ )$ is the effective transfer coefficient for phosphorus from drainage basin *DB* to its river mouth discharging into the relevant sea region.

$a_{DBm\_\max}$ reports the maximum feasible level of abatement for measure *m* in drainage basin *DB*

**Note that here we are summing load reductions from all drainage basins whose river mouths discharge into the sea region concerned: i.e. we are not allowing for any transport of nutrient (reductions) between sea regions.*

5. Data and measures

The nutrient reduction measures considered in BALTCOST version 8.0. are:

- reductions in fertiliser applications to arable crops (N abatement) (see annex 2.1.)
- catch crops under spring-sown cereals (N abatement) (see annex 2.2)
- reductions in livestock numbers (N & P abatement) (see annex 2.3.)
- restoring wetlands on agricultural soils (N & P abatement) (see annex 2.4.)
- improving wastewater treatment (WWT) (N & P abatement) (see annex 2.5.)

More measures will be implemented in the model in the near future. These are:

- constructing wetlands on agricultural and non-agricultural land
- NOx reductions from power plants and ships (see annex 2.6)

Cost functions for the measures (described in RECOCA Deliverable 7.1, as well as in the annexes to this report) describe the cost of implementing a particular abatement measure at a particular intensity within the geographical area of each of the 22 main drainage basins across the 9 countries, each drainage basin draining from (predominantly) one country into a specific Baltic Sea region. The countries, drainage basins and sea regions are shown in Figure 1.

For a number of measures the cost functions are estimated using data from one or a few countries, and these costs are adjusted to provide adjusted cost estimates for the other countries. The estimated Standard Gross Margins and Standard Outputs of crops and livestock are used to adjust the costs of the agricultural measures, as well as the costs of wetland restoration.

Biophysical and geographic data on cropping areas, livestock numbers, potential for wetland restoration and population numbers connected to primary, secondary or tertiary WWT are available at 10 x 10km grid cell resolution across all the 9 countries. The data and how they are used are described in the annexes for each of the measures included in the model. Most of these data are described in Andersen et al (2011).

Data from MESAW modelling (Stålnacke et al, 2011) detailing N retention in groundwater and surface water, and P retention in surface water are available for 117 separate watersheds (see Table 4 and 5 in Annex 1) across the 9 countries. After the description of the cost-minimisation problem, the modelling of the retention is described.

6. Modelling abatement measure-specific N and P retentions per drainage basin

Not all of the N or P loads applied at the land surface appear as N or P loads in the Baltic Sea region into which that land surface drains. A proportion of the N or P load is lost or ‘retained’ through naturally occurring chemical processes in the soil or water media through which the pollutants are transported. The retention is thus very influential over cost-effectiveness as it influences the effectiveness of the measures in terms of nutrient load reduction when the load reductions are measured at the river mouth.

The retention in soil, groundwater and rivers are measured using the statistical model MESAW and by the Hydraulic Load method (HL). Documentation of MESAW can be found as a RECOCA deliverable (Stålnacke et al 2011).

The proportion of the N or P nutrient load which is retained in this way is conveniently expressed as a single retention coefficient for the environmental compartment and nutrient concerned. For example, for N retention in the soil and groundwater compartment:

$$Ngw\_retention = \left(\frac{\text{N load out of compartment (kg)}}{\text{N load entering compartment (kg)}} \times 100 \right)\% \qquad (1)$$

The ground water and surface water retention coefficients which the MESAW model predicts for N and P differ across the 117 watersheds depending on factors such as soil type, porosity, rainfall, slope, geology, acidity, volumetric flow etc. BALTCOST models the implementation of abatement measures at drainage basin resolution. Since each drainage basin comprises between 1 and 16 watersheds, it was necessary to produce abatement measure-specific estimates of N and P retention in groundwater and surface water at drainage basin resolution.

Abatement measure-specific N and P retentions for the 22 drainage basins were calculated using area-weighting or numbers-weighting of the relevant N and P producing units (hectares of particular crops, hectares of potentially restorable wetlands, numbers of particular livestock classes and populations upgraded to improved levels of WWT) at 10 x 10km square resolution across the (1 to 16 of 117) watersheds within a particular drainage basin. For example, the area-weighted groundwater N retention for N abatement by reducing fertilizer applications to barley was calculated as:

$$Ngw\_retention_{DB}^{Barley} = \sum_{j=1}^{N_{WS}^{DB}} \sum_{i=1}^{N_{cell}^{WS}} \frac{a_i^{Barley}}{A_{DB}^{Barley}} R_j^{Ngw} = \frac{1}{A_{DB}^{Barley}} \sum_{j=1}^{N_{WS}^{DB}} R_j^{Ngw} \sum_{i=1}^{N_{cell}^{WS}} a_i^{Barley}$$

(2)

where:

$Ngw\_retention_{DB}^{Barley}$ = average groundwater N retention for reduced fertilizer applications to barley across the drainage basin

a_i^{Barley} = area of barley in 10 x 10km grid cell i

A_{DB}^{Barley} = total area of barley in the entire drainage basin

R_j^{Ngw} = N retention by groundwater within watershed j

N_{cell}^{WS} = total number of 10 x 10km grid cells in watershed j

N_{WS}^{DB} = total number of watersheds in drainage basin

i indexes 10 x 10km grid cells within a watershed

j indexes watersheds within a drainage basin

Drainage basin weighted-average retentions for the other abatement measures are calculated similarly, with livestock numbers or population sizes within 10 x 10km grid cells replacing the grid-cell specific crop area as appropriate in Eqn (2). The resulting measure-specific retentions are shown in Tables 6 and 7 in annex 1.

N and P retention also means that the reductions in N and P loads entering the receiving Baltic Sea basin will (typically) be lower than the reductions in N and P emissions at source. For example, for land-based measures (reduced fertilizer applications, reduced livestock numbers, catch crops), the effective N reduction in the receiving sea region is calculated as:

$$\begin{aligned} N \text{ load reduction in sea} &= N \text{ load reduction at source} \cdot (1 - Ngw\_retention) \cdot (1 - Nsw\_retention) \\ &= N \text{ load reduction at source} \cdot TN_{land\_sea} \end{aligned} \tag{3}$$

where TN_{land_sea} is a single N transport coefficient which captures the combined impact of groundwater and surface water N retention on the effectiveness of land-based N abatement measures with regard to reducing N loadings in the receiving Baltic Sea region.

For those measures which reduce nitrogen input to surface waters directly (restored wetlands and improved WWT), the effective N reduction in the receiving sea region is:

$$\begin{aligned} N \text{ load reduction in sea} &= N \text{ load reduction at source} \cdot \left(1 - Nsw\_retention\right) \\ &= N \text{ load reduction at source} \cdot TN_{river\_sea} \end{aligned} \quad (4)$$

where TN_{river_sea} is the N transport coefficient which captures the impact of surface water N retention on the effectiveness of river-based N abatement measures with regard to reducing N loadings in the receiving Baltic Sea region.

Current retention modelling approaches are unable to estimate groundwater retention coefficients for P. BALTCOST modelling therefore assumed groundwater P retention coefficients for the 117 watersheds to be the same as the groundwater N retention coefficients estimated by MESAW. This assumption is only relevant for calculating the cost-effectiveness of the livestock reduction measure for P abatement as this is the only land-based P reduction measure in the BALTCOST model.

7. Results from BALTCOST Drainage Basin scale abatement cost minimisation model for nutrient reductions in Baltic Sea regions

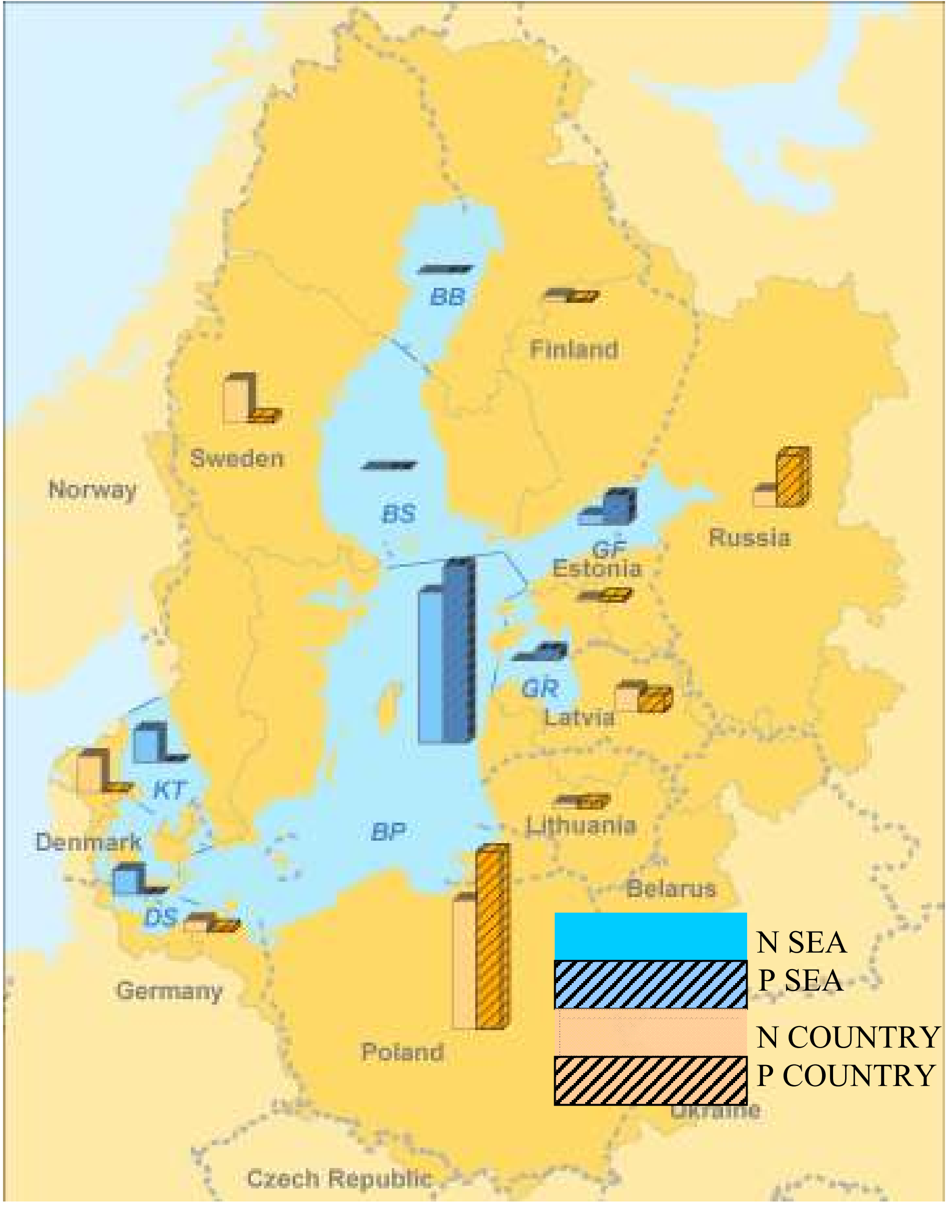
7.1. Load reduction targets

The Baltic Sea Action Plan (BSAP) contains HELCOM-derived targets for N and P load reductions in the different Baltic Sea regions (Table 1 & HELCOM 2007).

Table 4: HELCOM BSAP load reduction targets for N and P

Sea Region ID	N load reduction target (tonnes)	P load reduction target (tonnes)
BB	0	0
BS	0	0
BP	94000	12500
GF	6000	2000
GR	0	750
DS	15000	0
KT	20000	0
Total	135000	15250

Figure 2: HELCOM BSAP load reduction targets for N and P, sea and countrywise targets



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The map illustrates the targets set by HELCOM (2007) in the sea regions (Bothnian Bay BB, Bothnian Sea BS, Baltic Proper BP, Gulf of Finland GF, Gulf of Riga GR, Danish Straits DS, Kattegat KT). The HELCOM BSAP targets are also distributed at country level. In the results presented here BALTCOST 8.0. is used to estimate the cost-effective implementation of the sea-region-specific targets, and the country-specific targets are not modelled in this report. BALTCOST can, however, be configured to model the country-specific targets if so required.

The results below report the minimum cost configuration of N and P abatement measures identified by BALTCOST at drainage basin spatial resolution for delivering load reductions which match the BSAP load reduction targets as fully as possible, given the measure-specific maximum abatement capacities implemented in BALTCOST.

BALTCOST results indicate that the BSAP load reduction targets can be delivered within the modelled measure-specific maximum abatement capacities in all instances except for N reductions in the Danish Straits (DS) and P reductions in the Baltic Proper (BP). Load targets for the BP and DS sea regions were reduced appropriately (Table 5) until the required reductions could be delivered within the capacities of the measures as modelled in BALTCOST. The minimum cost configuration of abatement measures identified to deliver the Table 5 load reduction targets are described in the next section.

Table 5: Maximum load reduction targets for N and P which could feasibly be delivered within the measure-specific maximum abatement capacities implemented in BALTCOST. (DS 88 % of BSAP target for N reduction; BP 74% of BSAP target for P reduction).

Sea Region ID	N load reduction target (tonnes)	P load reduction target (tonnes)
BB	0	0
BS	0	0
BP	94000	*9290 (74% of BSAP)*
GF	6000	2000
GR	0	750
DS	*13120 (88% of BSAP)*	0
KT	20000	0
Total	133120	12040

7.2. Total cost of nutrient abatement: distribution of abatement costs and load reductions between countries and sea regions

The lowest cost configuration of drainage basin-specific abatement measures which achieves the load reduction targets of Table 5 delivers the N and P reductions shown in Table 3 in the various sea regions. Nutrient reductions can exceed the targets specified for particular sea regions because the livestock, wetlands and WWT measures deliver both N and P reductions. Thus, for example, increasing implementation of the wetlands measure to satisfy a P load reduction target will also deliver N load reductions, whether or not these N load reductions are required – and vice versa.

Table 6: N and P reductions delivered by the lowest cost combination of drainage basin-specific abatement measures which achieve the load reduction targets of Table 5

Sea Region ID	N load reduction achieved (tonnes) [% of BSAP target]	P load reduction achieved (tonnes) [% of BSAP target]
BB	0 [100]	0 [100]
BS	0 [100]	0 [100]
BP	130015 [138]	9290 [74]
GF	29720 [495]	2000 [100]
GR	21276 [*]	750 [100]
DS	13120 [88]	407 [*]
KT	20000 [100]	55 [*]
Total	214131	12503

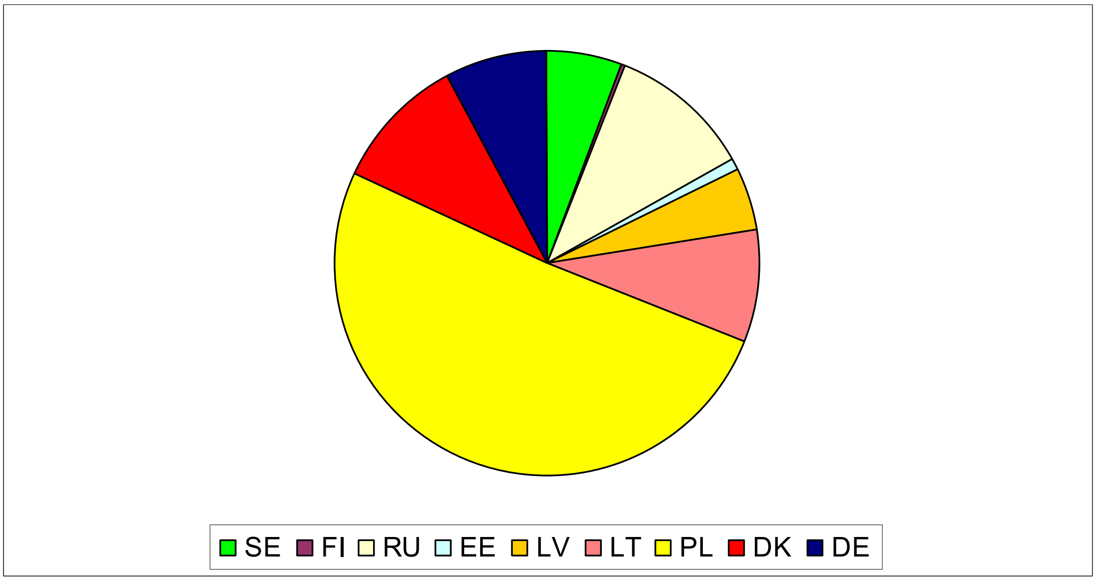
[*] denotes nutrient reduction delivered against a load reduction target of 0 tonnes, because the other nutrient reduction target should be achieved.

The total annual cost of delivering the load reduction targets of Table 5 using the lowest cost combination of drainage basin-specific abatement measures is distributed between countries as shown in Table 7 and Figure 3.

Table 7: Total annual costs of delivering the nutrient reduction targets of Table 5 using the lowest cost combination of drainage basin-specific abatement measures

Country ID	Total annual cost of nutrient load reductions (Million Euros)
SE	271.7
FI	17.2
RU	506.9
EE	32.3
LV	226.7
LT	405.9
PL	2385.5
DK	472.1
DE	370.8
Total	4689.2

Figure 3: Distribution between countries of the total annual costs of delivering the nutrient reduction targets of Table 5 using the lowest cost combination of drainage basin-specific abatement measures.



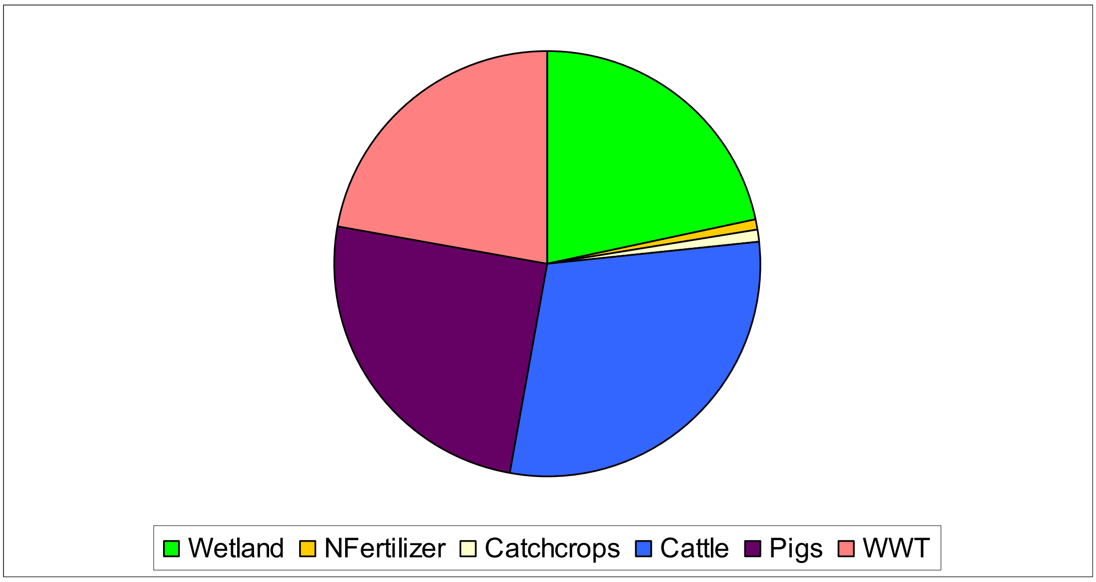
The total annual costs are estimated to 4689 million EUR, and a major part of these costs are in Poland. This does not mean, however, that the costs should be borne by the citizens of Poland as these costs could be distributed between the countries around the Baltic. Analyses of such cost-sharing schemes are outside the scope of this work and this report.

In the next section the distribution of abatement measures undertaken in the 22 drainage basins to fulfil the load reduction targets is explained and analysed in further detail.

7.3. Distribution of abatement costs and cost effectiveness between abatement measures

Figure 4 shows the distribution of total annual abatement costs between abatement measures. (Corresponding data in Results Data Annex: Table R.1).

Figure 4: Distribution between abatement measures of the total annual costs of delivering the nutrient reduction targets of Table 5 using the lowest cost combination of drainage basin-specific abatement measures.



The average cost effectiveness of the different abatement measures (Euros per tonne of N or P load reduced in the sea) across the 9 countries is shown in Tables 8 and 9.

The wetlands, livestock reductions and WWT measures deliver both N and P reductions simultaneously, and this is an important explanation for the implementation of these measures, besides the costs and the load reduction effects.

For these measures, the average cost effectiveness results reported in Tables 8 and 9 assume that the full expenditure on the measure is incurred in reducing the nutrient load reported in the relevant column, i.e. the N reduction cost effectiveness reported for WWT in Table 8 assumes that all of the expenditure on WWT is incurred in delivering the N reduction achieved by WWT, whereas the P reduction cost effectiveness reported for WWT in Table 9 also assumes that all of the expenditure on WWT is incurred in delivering the P reduction achieved by WWT.

Table 8: Average cost effectiveness of N abatement measures (thousand Euros per tonne N load reduced in the sea) across the 9 Baltic littoral countries.

Country	Wetland*	NFertilizer	Catchcrops	Cattle*	Pigs*	WWT*	Total*
SE	12.0	2.9	6.2	151.2	225.9	28.4	20.4
FI	*not used*	*not used*	*not used*	*not used*	*not used*	48.1	48.1
RU	2.8	*not used*	*not used*	292.6	842.2	78.8	15.8
EE	2.4	*not used*	*not used*	*not used*	*not used*	97.0	4.3
LV	4.7	*not used*	*not used*	20.6	43.7	25.4	13.2
LT	92.5	*not used*	*not used*	53.1	102.2	16.3	44.3
PL	7.1	*not used*	*not used*	102.6	228.6	21.2	22.9
DK	9.3	4.3	5.4	187.5	315.7	59.8	24.0
DE	11.8	8.5	8.4	142.2	212.5	136.4	35.3
Total	7.2	3.9	5.8	79.7	211.6	33.5	21.9

* Measure delivers both N and P load reductions. Cost effectiveness reported here assumes that all expenditure on the measure is incurred to reduce N loads.

Table 8 indicates that the general cost effectiveness ranking of N abatement measures, from most to least cost effective, is: fertilizer reduction, catch crops, wetlands, WWT, cattle reduction, pig reduction. The ranking of measures by average cost effectiveness of N reduction varies somewhat between countries – for example in Germany, on average, catch crops are more cost effective than fertiliser reductions for delivering N load reductions in the sea. The average cost effectiveness ranking of N abatement between countries depends on the local cost of implementing the measures at source, the ground and surface water retentions between source and the sea and the national capacities for implementing the different N abatement measures.

It can be seen that N fertiliser reductions and catch crops are not undertaken in Finland, Russia, Estonia, Latvia and Poland,. The reason is that the targets for N load reduction in the sea regions into which the loads from these countries drain are satisfied by improving WWT, which is typically a very cost-effective for P reductions. This influences the choice of measures also for N reductions in these countries.

Table 9: Average cost effectiveness of P abatement measures (thousand Euros per tonne P load reduced in the sea) across the 9 Baltic littoral countries.

Country	Wetland*	NFertilizer	Catchcrops	Cattle*	Pigs*	WWT*	Total*
SE	745.7	*not used*	*not used*	1859.3	1424.7	96.0	113.5
FI	*not used*	*not used*	*not used*	*not used*	*not used*	201.2	177.1
RU	395.6	*not used*	*not used*	5455.1	5895.1	206.5	167.0
EE	449.3	*not used*	*not used*	*not used*	*not used*	297.1	285.6
LV	457.4	*not used*	*not used*	731.7	745.6	113.1	62.7
LT	549.2	*not used*	*not used*	1800.4	1782.7	63.3	66.4
PL	1196.7	*not used*	*not used*	4396.6	4206.9	57.5	73.3
DK	1374.8	*not used*	*not used*	3262.0	2776.4	305.4	116.8
DE	1518.4	*not used*	*not used*	3670.2	2730.8	367.7	123.2
Total	865.6	*not used*	*not used*	2552.0	3255.9	100.3	85.4

* Measure delivers both N and P load reductions. Cost effectiveness reported here assumes that all expenditure on the measure is incurred to reduce P loads.

Comparison between Tables 8 and 9 shows that P abatement is considerably more expensive than N abatement, per tonne of nutrient load reduction achieved in the sea. Table 9 indicates that the general cost effectiveness ranking of P abatement measures, from most to least cost effective, is: WWT, wetlands, cattle reduction, pig reduction. The ranking of measures by average cost effectiveness of P reduction varies somewhat between countries – for example in Russia and Latvia, it is more cost effective, on average, to reduce pig numbers rather than cattle numbers in order to achieve P load reductions in the sea, whereas the opposite is true elsewhere. The average cost effectiveness ranking of P abatement measures between countries depends on the local cost of implementing the measures at source, the surface water retentions between source and the sea and the national capacities for implementing the different P abatement measures.

The RECOCA model, developed as part of WP7 and described in deliverable 7.3., has also been used to model BSAP, but only N reduction targets are modelled. Thus the costs results from the RECOCA model runs are much lower than the estimated BALTCOST 8.0.costs presented here, and the results are not comparable.

7.4. Baltic Proper: distribution of N and P abatement at source between measures and drainage basins

As mentioned previously, there are problems in achieving the load reduction targets in the Baltic proper and the Danish Straits. We therefore perform a more detailed assessment for these two sea regions and the drainage basins loads to these sea regions.

To provide the illustrative example on the Baltic Proper, Figure 5 shows the distribution of N abatement at source between abatement measures in the lowest cost combination of drainage basin-specific abatement measures which delivers the load reductions of Table 6 in the Baltic Proper sea region. (Corresponding data in Results Data Annex: Table R.2)

It can be seen from figure 5 and 6 that reductions are undertaken in pig production in Poland, as well as WWTP, and as a third measure cattle production is also reduced. The main driver behind the choice of these measures is the fulfilment of the P load targets. Furthermore, the fact that no transport between sea regions is anticipated makes it less interesting to reduce P loads in Russia and Finland as these reductions have no effect in the Baltic Proper in this model. The inclusion of transport between the sea regions Gulf of Finland and Baltic Proper would therefore most certainly lead to implementation of waste water treatment in Russia. This part of the model can therefore also be improved.

It can also be noted that the inclusion of a measure regarding improved manure storage, handling and timing could substitute the use of these measures. and that such measures should be included in the future, but require that data on the current handling, storage and timing in pig and cattle production are available, as well as the effect of these measures on the N and P load reductions to the sea. .

Figure 5: The distribution of N abatement at source between abatement measures in the lowest cost combination of drainage basin-specific abatement measures which delivers the load reductions of Table 6 in the Baltic Proper sea region.

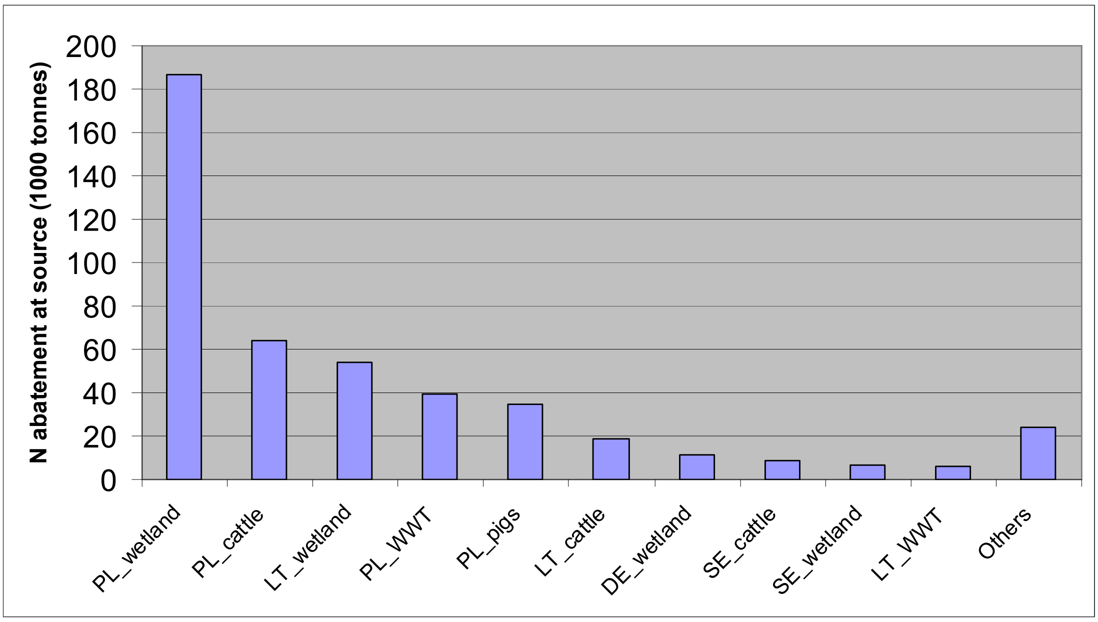
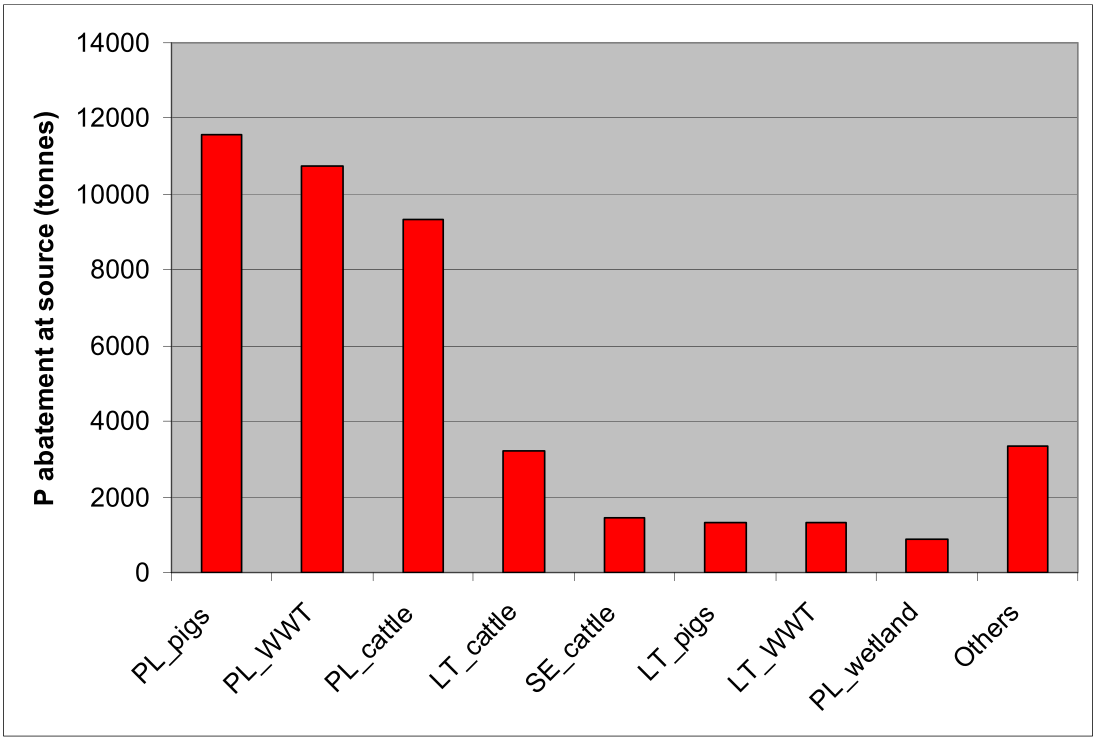


Figure 6 shows the distribution of P abatement at source between abatement measures in the lowest cost combination of drainage basin-specific abatement measures which delivers the load reductions of Table 6 in the Baltic Proper sea region. (Corresponding data in Results Data Annex: Table R.3)

Figure 6: The distribution of P abatement at source between abatement measures in the lowest cost combination of drainage basin-specific abatement measures which delivers the load reductions of Table 3 in the Baltic Proper sea region.



7.5. Danish Straits: distribution of N abatement at source between measures and drainage basins

Figure 7 shows the distribution of N abatement at source between abatement measures in the lowest cost combination of drainage basin-specific abatement measures which delivers the load reductions of Table 6 in the Danish Straits sea region. (Corresponding data in Results Data Annex: Table R.4)

Figure 7: The distribution of N abatement at source between abatement measures in the lowest cost combination of drainage basin-specific abatement measures which delivers the load reductions of Table 6 in the Danish Straits sea region.

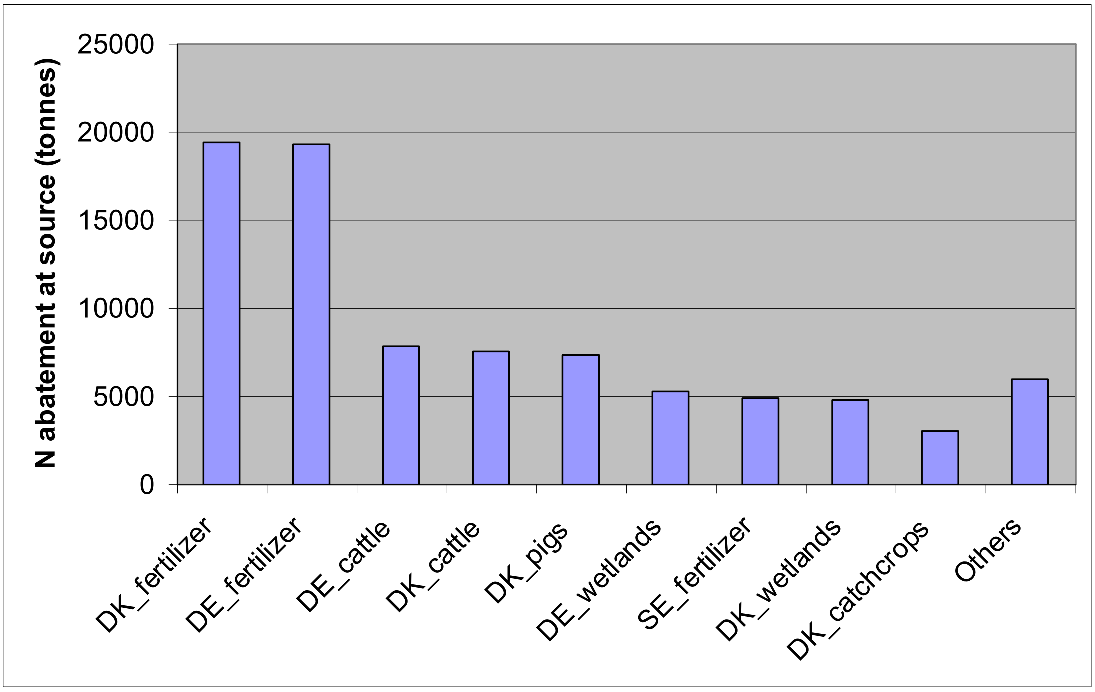
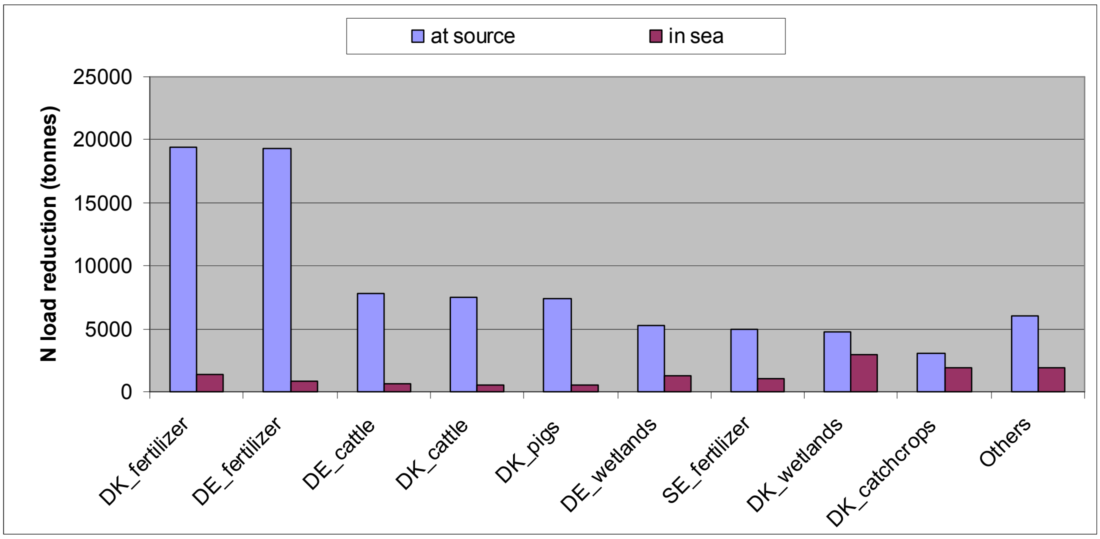


Figure 7 shows that delivery of the N reduction target in the Danish Straits requires use of most N abatement measures except waste water treatment, which is a costly N reduction measure.

7.6. Effect of N and P retentions

The considerable effect which N and P retentions in groundwater and surface water, together with the leaching function for fertilizer applications to arable crops and the applied utilisation factors for animal manures, exert over the requirement to implement N and P abatement at source in order to deliver the desired N and P load reductions in the receiving Baltic Sea regions is illustrated in Figure 8. Figure 8 compares the effective N reductions achieved in the Danish Straits with the N abatement actually implemented at source for the various N abatement measures undertaken. (Corresponding data in Results Data Annex: Table R.4)

Figure 8: Comparison of N abatement at source with N load reductions achieved in the Danish Straits by the various N abatement measures.



These results indicate that the effect of the retention is considerable in this region. Retentions are typically somewhat lower in the drainage basins in the northern parts of Sweden, Finland and the eastern parts of the Baltic, but in all drainage basins around the Baltic retention plays a major role in determining the resulting load reductions. In the report for deliverable 8.2. we have paid attention to the retentions and the assumptions behind these, and have undertaken a sensitivity analysis to investigate how different assumptions regarding retentions affect the cost-effectiveness of the different abatement measures and the total abatement cost.

7.7. Discussion of results

BALTCOST results suggest that it should be possible to achieve the BSAP load reduction targets for N and P in most Baltic Sea regions, with the exception of the P load target in the Baltic Proper and the N reduction target in the Danish Straits, where only 74% and 88%[1], respectively, of the desired BSAP load reductions can be achieved. These results indicate that the targets are hard to achieve, and that more abatement measures are required to fulfil these targets.

Regarding N load reductions, additional measures can be used to reduce atmospheric loads from power plants as well as from ships. Furthermore constructed wetlands on non-agricultural land can be used to reduce both N and P loads to the sea. Both N and P loads, but especially P loads, can be reduced by buffer zones or equivalent measures that reduce emissions by reducing erosion from agricultural soils and forests.

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[1] On average the total N load reduction achieved in the BALTCOST 8.0 modelling of BSAP is 133120 tons annually, i.e. 99% of the BSAP target, but this average is caused by over delivery of the targets in some sea regions and the under delivery in Danish straits, and therefore the average doesn't give the right interpretation of the target achievement. For P the achieved total reduction is 12503 tons annually ,which in average is 82% of the BSAP target. Again, this is caused by over delivery of the targets in some sea regions and the under delivery in the Baltic Proper.

There would also appear to be considerable potential for reducing N and P loads into the Baltic by improving manure handling (storage and application) in those regions where manure handling is currently inadequate and where, as a result, utilisation of nutrients from animal manures is ineffective. Improved integration between livestock production and crop production, enabling nutrients to be utilised more effectively, could also be adopted as a potential additional measure to reduce nutrient loads into the Baltic.

The minimised total cost of delivering these load reductions across the 9 Baltic littoral countries is estimated to be 4.69 billion Euros, annually. Comparison of N and P reductions at source and at sea shows that nutrient retention is highly influential over the costs incurred in fulfilling the load reduction targets. In the (unrealistic) situation in which nutrient retention in the drainage basins is assumed to be zero the estimated costs of delivering the BSAP nutrient reduction targets are much lower (in total 714 million Euro per annum). (see deliverable 8.2.). The comparison made using the RECOCA model (deliverable 7) identifies the very considerable influence which the spatial resolution at which the nutrient retentions are modelled exerts over the minimum cost configuration of abatement measures. Disregarding retention is clearly unrealistic, and the detailed modelling of nutrient retention is one of the major differences between BALTCOST, RECOCA and earlier models developed to assess cost-minimising strategies for nutrient reductions in the Baltic Sea (Gren and Wulff 2004, Schou et al 2007, Elofsson 2011, Gren 2008). The inclusion of N and P retention estimates is one of the major reasons for the higher costs predicted by BALTCOST compared to the results presented by e.g. Gren (2008).

In deliverable 9 (9.1. and 9.2) the costs of full delivery of the BSAP are compared to the costs of delivering lower reductions for both N and P. This analysis shows that abatement costs increase dramatically per extra unit of P load reductions in the Baltic Proper, and also that abatement costs are increasing, but to a lower extent, for increasing N load reductions. We refer to deliverable 9 for a more detailed presentation and discussion of these results.

Results Data annex

Table R.1: Distribution between abatement measures of the total annual costs of delivering the nutrient reduction targets of Table 2 using the lowest cost combination of drainage basin-specific abatement measures.

Abatement measure	Total annual cost (Million Euros)
Wetland	1011.4
N Fertilizer	46.6
Catchcrops	39.1
Cattle	1382.1
Pigs	1163.3
WWT	1046.6

Total	4689.2

Table R.2: Distribution of N abatement at source between abatement measures in the lowest cost combination of drainage basin-specific abatement measures which delivers the load reductions of Table 3 in the Baltic Proper sea region.

Abatement measure in drainage basin	N abatement at source (1000 tonnes)
PL_wetlands	186.9
PL_cattle	63.7
LT_wetlands	54.1
PL_WWT	39.0
PL_pigs	34.8
LT_cattle	18.7
DE_wetlands	11.3
SE_cattle	8.6
SE_wetlands	6.6
LT_WWT	6.0
Others	24.1
Total	453.9

Table R.3: Distribution of P abatement at source between abatement measures in the lowest cost combination of drainage basin-specific abatement measures which delivers the load reductions of Table 3 in the Baltic Proper sea region.

Abatement measure in drainage basin	P abatement at source (tonnes)
PL_pigs	11595
PL_WWT	10733
PL_cattle	9324
LT_cattle	3209
SE_cattle	1442
LT_pigs	1330
LT_WWT	1317
PL_wetland	872
Others	3343
Total	43166

Table R.4: Distribution of N abatement at source between abatement measures in the lowest cost combination of drainage basin-specific abatement measures which delivers the load reductions of Table 3 in the Danish Straits sea region.

Abatement measure in drainage basin	N abatement at source (tonnes)
DK_fertilizer	19453
DE_fertilizer	19301
DE_cattle	7808
DK_cattle	7514
DK_pigs	7390
DE_wetlands	5312
SE_fertilizer	4939
DK_wetlands	4779
DK_catchcrops	3045
Others	5965
Total	85505

Table R.5: Comparison of N abatement at source with N load reductions achieved in the Danish Straits by the various N abatement measures.

Abatement measure in drainage basin	N abatement at source (tonnes)	N load reduction achieved in Danish Straits (tonnes)	Effectiveness (%)
DK_fertilizer	19453	1085	5.6
DE_fertilizer	19301	893	4.6
DE_cattle	7808	582	7.5
DK_cattle	7514	486	6.5
DK_pigs	7390	453	6.4
DE_wetlands	5312	1280	24.1
SE_fertilizer	4939	1061	21.5
DK_wetlands	4779	2914	61.0
DK_catchcrops	3045	1857	61.0
Others	5965	1890	31.7
Total	85505	12500	14.7

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Annex 1. Tables.

Table 4: The 117 watersheds modelled in BALTCOST

Watershed ID	Watershed Name	Drainage Basin (majority of 10 x 10km grid squares)
1	Rickleån	SE-BB
2	Skellefte älv	SE-BB
4	Pite älv	SE-BB
5	Alterälven	SE-BB
6	Lule älv	SE-BB
8	Kalix älv	SE-BB
10	Torne älv	SE-BB
12	Kemijoki	FI-BB
14	Iijoki	FI-BB
15	Kiiminkijoki	FI-BB
16	Oulujoki	FI-BB
21	Kokemäenjoki	FI-BS
24	Forsmarksån	SE-BS
25	Dalälven	SE-BS
26	Gavleån	SE-BS
27	Ljusnan	SE-BS
28	Delångersån	SE-BS
29	Ljungan	SE-BS
31	Indalsälven	SE-BS
33	Ångermanälven	SE-BS
35	Ume älv	SE-BS
41	Kymijoki	FI-GF
42	Neva	RU-GF
43	Vironjoki	FI-GF
46	Narva	RU-GF
47	Kelia	EE-BP
61	Gauja	LV-GR
62	Daugava	LV-GR
63	Lielupe	LV-GR
71	Råneälven	SE-BB
72	Töreälven	SE-BB
80	Venta	LV-BP
83	Neman	LT-BP
84	Pregolia	RU-BP
85	Vistula	PL-BP
87	Odra	PL-BP
91	Helge å	SE-BP
93	Mörrumsån	SE-BP
95	Lyckebyån	SE-BP
96	Ljungbyån	SE-BP
97	Emån	SE-BP
98	Botorpströmmen	SE-BP
99	Motala ström	SE-BP
100	Nyköpingsån	SE-BP
101	Norrström	SE-BP

103	Kasari	EE-GR
131	Simojoki	FI-BB
132	Kuivajoki	FI-BB
142	Rönne å	SE-KT
143	Lagan	SE-KT
145	Nissan	SE-KT
147	Ätran	SE-KT
149	Viskan	SE-KT
151	Göta älv	SE-KT
171	Siikajoki	FI-BB
172	Pyhäjoki	FI-BB
173	Kalajoki	FI-BB
174	Lestijoki	FI-BB
175	Perhonjoki	FI-BB
176	Ähtävänjoki	FI-BB
177	Lapuanjoki	FI-BB
178	Kyrönjoki	FI-BB
201	Laihianjoki	FI-BB
202	Närpiönjoki	FI-BS
205	Isojoki	FI-BS
221	Eurajoki	FI-BS
222	Sirppujoki	FI-BS
231	Aurajoki	FI-BS
232	Paimionjoki	FI-BS
233	Uskelanjoki	FI-BS
234	Kiskonjoki	FI-BS
250	Karvianjoki	FI-BS
341	Gideälven	SE-BS
342	Lögdeälven	SE-BS
343	Öreälven	SE-BS
401	Vantaanjoki	FI-GF
402	Mustijoki	FI-GF
403	Porvoonjoki	FI-GF
404	Koskenkylänjoki	FI-GF
405	Iilolanjoki	FI-GF
601	Pärnu	EE-GR
602	Salaca	LV-GR
1011	Coast DE & Arkona Basin	DE-BP
1012	Coast DE & Bornholm Basin	DE-BP
1013	Coast DE & Fehmarn Belt	DE-DS
2011	Coast DK & Arkona Basin	DK-DS
2012	Coast DK & Bornholm Basin	DK-BP
2013	Coast DK & Southern Kattegat	DK-KT
2014	Coast DK & Samso Belt	DK-DS
2015	Coast DK & Fehmarn Belt	DK-DS
2016	Coast DK & The Sound	DK-DS
2017	Coast DK & Northern Kattegat	DK-KT
2018	Coast DK & Central Kattegat	DK-KT
3011	Coast EE & Baltic Proper	EE-BP
3012	Coast EE & Gulf of Finland	EE-GF
3013	Coast EE & Gulf of Riga	EE-GR
4011	Coast FI & Bothnian Bay	FI-BB
4012	Coast FI & Bothnian Sea	FI-BS
4013	Coast FI & Baltic Proper	FI-GF

4014	Coast FI & Gulf of Finland	FI-GF
5011	Coast LT & Baltic Proper	LT-BP
6011	Coast LV & Baltic Proper	LV-BP
6012	Coast LV & Gulf of Riga	LV-GR
7011	Coast PL & Bornholm Basin	PL-BP
7012	Coast PL & Baltic Proper	PL-BP
8011	Coast RU & Baltic Proper	RU-BP
8012	Coast RU & Gulf of Finland	RU-GF
9011	Coast SE & The Sound	SE-DS
9012	Coast SE & Arkona Basin	SE-BP
9013	Coast SE & Bornholm Basin	SE-BP
9014	Coast SE & Baltic Proper	SE-BP
9015	Coast SE & Bothnian Bay	SE-BB
9016	Coast SE & Bothnian Sea	SE-BS
9018	Coast North of Northern Kattegat	SE-KT
9019	Coast SE & Northern Kattegat	SE-KT
9020	Coast SE & Central Kattegat	SE-KT
9021	Coast SE & Southern Kattegat	SE-KT

Table 5: 117 watersheds, groundwater N retentions (N_{gw}) and surface water N (N_{sw}) and P (P_{sw}) retentions predicted by the MESAW model

Watershed ID	Watershed Name	Nutrient retentions		
		N_{gw} (%)	N_{sw} (%)	P_{sw} (%)
1	Rickleån	6	44	12
2	Skellefte älv	0	52	24
4	Pite älv	1	39	21
5	Alterälven	0	8	5
6	Lule älv	0	46	28
8	Kalix älv	0	18	23
10	Torne älv	19	37	31
12	Kemijoki	27	37	34
14	Iijoki	6	40	22
15	Kiiminkijoki	12	26	13
16	Oulujoki	9	59	30
21	Kokemäenjoki	16	54	30
24	Forsmarksån	5	26	5
25	Dalälven	25	41	28
26	Gavleån	31	45	13
27	Ljusnan	32	35	25
28	Delångersån	41	54	14
29	Ljungan	18	42	22
31	Indalsälven	0	37	28
33	Ångermanälven	0	46	30
35	Ume älv	11	43	28
41	Kymijoki	12	70	36
42	Neva	0	34	57
43	Vironjoki	15	18	5
46	Narva	59	56	37
47	Kelia	0	3	5

61	Gauja	10	13	17
62	Daugava	0	22	39
63	Lielupe	9	15	22
71	Råneälven	33	20	13
72	Töreälven	0	9	6
80	Venta	26	16	19
83	Neman	57	30	40
84	Pregolia	100	47	13
85	Vistula	68	32	48
87	Odra	76	30	42
91	Helge å	28	38	15
93	Mörrumsån	36	63	19
95	Lyckebyån	22	34	8
96	Ljungbyån	71	11	7
97	Emån	60	44	16
98	Botorpströmmen	64	54	12
99	Motala ström	30	73	30
100	Nyköpingsån	59	62	20
101	Norrström	72	60	30
103	Kasari	10	4	11
131	Simojoki	0	12	13
132	Kuivajoki	0	22	9
142	Rönne å	0	22	11
143	Lagan	13	54	20
145	Nissan	6	42	14
147	Ätran	0	35	14
149	Viskan	0	37	13
151	Göta älv	0	59	40
171	Siikajoki	33	19	13
172	Pyhäjoki	21	38	14
173	Kalajoki	22	28	14
174	Lestijoki	52	6	7
175	Perhonjoki	37	23	11
176	Ähtävänjoki	83	40	15
177	Lapuanjoki	46	23	13
178	Kyrönjoki	36	14	13
201	Laihianjoki	60	4	8
202	Närpiönjoki	27	7	7
205	Isojoki	49	5	8
221	Eurajoki	17	60	15
222	Sirppujoki	66	10	9
231	Aurajoki	37	2	6
232	Paimionjoki	18	14	7
233	Uskelanjoki	59	7	6
234	Kiskonjoki	50	36	9
250	Karvianjoki	18	30	14
341	Gideälven	22	29	13
342	Lögdeälven	28	20	9
343	Öreälven	32	15	11
401	Vantaanjoki	38	26	10
402	Mustijoki	26	13	6
403	Porvoonjoki	10	13	8
404	Koskenkylänjoki	49	32	8
405	Iilolanjoki	71	21	11

601	Pärnu	28	6	14
602	Salaca	0	1	12
1011	Coast DE & Arkona Basin	84	7	8
1012	Coast DE & Bornholm Basin	56	23	12
1013	Coast DE & Fehmarn Belt	76	29	14
2011	Coast DK & Arkona Basin	0	4	8
2012	Coast DK & Bornholm Basin	0	2	7
2013	Coast DK & Southern Kattegat	93	4	8
2014	Coast DK & Samso Belt	77	7	8
2015	Coast DK & Fehmarn Belt	76	22	12
2016	Coast DK & The Sound	0	81	43
2017	Coast DK & Northern Kattegat	100	23	11
2018	Coast DK & Central Kattegat	49	14	10
3011	Coast EE & Baltic Proper	0	11	10
3012	Coast EE & Gulf of Finland	0	8	9
3013	Coast EE & Gulf of Riga	0	11	9
4011	Coast FI & Bothnian Bay	60	20	11
4012	Coast FI & Bothnian Sea	0	21	13
4013	Coast FI & Baltic Proper	94	19	11
4014	Coast FI & Gulf of Finland	31	23	12
5011	Coast LT & Baltic Proper	0	7	8
6011	Coast LV & Baltic Proper	1	16	10
6012	Coast LV & Gulf of Riga	0	12	12
7011	Coast PL & Bornholm Basin	73	8	9
7012	Coast PL & Baltic Proper	40	26	13
8011	Coast RU & Baltic Proper	32	44	19
8012	Coast RU & Gulf of Finland	100	17	9
9011	Coast SE & The Sound	33	9	9
9012	Coast SE & Arkona Basin	72	4	8
9013	Coast SE & Bornholm Basin	24	58	26
9014	Coast SE & Baltic Proper	5	23	12
9015	Coast SE & Bothnian Bay	16	39	17
9016	Coast SE & Bothnian Sea	78	37	16
9018	Coast North of Northern Kattegat	0	60	46
9019	Coast SE & Northern Kattegat	85	31	14
9020	Coast SE & Central Kattegat	0	6	8
9021	Coast SE & Southern Kattegat	63	32	14

Table 6: Area-weighted crop-specific groundwater N retentions for the arable fertilizer reduction N abatement measure in the 22 Drainage Basins, derived from MESAW retentions at 117 watershed resolution

Drainage Basin ID	Arable Crop													
	SWHE	GRAI	GRAE	RYEM	BARL	OATS	PULS	POTA	SUGB	RAPE	OFAR	MAIF	OFAO	FALL
DE-BP	61	61	60	60	61	60	60	61	61	61	60	60	60	60
DE-DS	76	76	76	76	76	76	76	76	76	76	76	76	76	76
DK-BP	6	7	1	7	8	1	5	23	77	3	2	4	2	6
DK-DS	68	68	71	68	69	66	70	71	67	69	71	74	73	68
DK-KT	59	55	61	57	57	58	54	54	89	59	54	54	53	57
EE-BP	0	0	100	0	0	0	0	0	100	0	0	100	100	100
EE-GF	1	0	100	1	1	1	0	1	100	1	1	100	100	100
EE-GR	17	16	100	17	17	17	16	17	7	17	17	11	100	100
FI-BB	50	38	45	42	42	43	48	44	52	46	37	100	37	42
FI-BS	23	15	11	20	19	18	20	17	19	19	17	18	17	19
FI-GF	49	27	34	39	34	30	44	30	42	39	24	43	22	35
LT-BP	56	56	100	56	56	57	57	57	56	56	56	56	100	100
LV-BP	20	17	100	19	19	18	22	19	19	21	19	21	100	100
LV-GR	5	3	100	3	4	2	3	3	5	6	3	7	100	100
PL-BP	70	70	74	70	70	70	68	69	71	72	69	73	76	76
RU-BP	87	76	100	79	77	82	77	74	75	87	71	97	100	100
RU-GF	46	51	10	43	37	25	42	45	32	50	29	59	4	18
SE-BB	13	12	12	19	13	13	19	13	100	19	14	100	13	13
SE-BP	41	34	34	37	47	51	46	37	38	44	38	100	38	46
SE-BS	56	37	37	56	44	49	65	33	100	66	35	100	29	46
SE-DS	33	33	33	33	33	33	33	33	33	33	33	100	33	33
SE-KT	10	7	7	11	10	4	9	14	31	10	7	100	10	5

Table 7: Area-weighted crop-specific surface water N retentions for the arable fertilizer reduction N abatement measure in the 22 Drainage Basins, derived from MESAW retentions at 117 watershed resolution

	Arable Crop													
Drainage Basin ID	SWHE	GRAI	GRAE	RYEM	BARL	OATS	PULS	POTA	SUGB	RAPE	OFAR	MAIF	OFAO	FALL
DE-BP	20	20	20	21	20	21	20	20	20	20	21	21	21	20
DE-DS	29	29	29	29	29	29	29	29	29	29	29	29	29	29
DK-BP	2	2	2	2	3	2	2	4	7	2	2	2	2	2
DK-DS	10	11	10	11	10	12	11	12	9	10	13	12	13	10
DK-KT	12	13	11	13	13	13	14	13	5	12	13	13	14	13
EE-BP	9	9	100	9	9	9	9	9	100	8	9	100	100	100
EE-GF	9	8	100	8	9	9	8	9	100	9	9	100	100	100
EE-GR	7	7	100	7	7	7	7	7	10	7	7	9	100	100
FI-BB	21	30	27	24	24	23	21	23	19	22	27	100	27	24
FI-BS	26	41	30	37	36	41	33	36	35	37	41	25	44	38
FI-GF	24	46	42	32	37	42	29	42	27	32	51	22	52	37
LT-BP	30	30	100	30	30	30	30	30	30	30	30	29	100	100
LV-BP	16	16	100	16	16	16	16	16	16	16	16	16	100	100
LV-GR	17	19	100	19	17	19	20	18	16	17	18	16	100	100
PL-BP	30	30	31	30	30	30	30	31	30	28	31	30	30	30
RU-BP	46	46	100	46	46	46	46	46	46	46	46	47	100	100
RU-GF	48	53	33	49	44	38	48	50	34	50	43	56	33	32
SE-BB	40	36	36	37	40	39	37	38	100	37	39	100	39	39
SE-BP	46	48	48	41	48	54	50	41	27	49	47	100	45	51
SE-BS	38	40	40	38	39	39	38	39	100	37	39	100	38	39
SE-DS	9	9	9	9	9	9	9	9	9	9	9	100	9	9
SE-KT	47	48	48	46	46	53	48	42	28	47	51	100	46	52

Table 8: Area-weighted or numbers-weighted groundwater N retentions for the cattle reduction (cattle), pig reduction (pigs) and catch crops (catch) N abatement measures in the 22 Drainage Basins, derived from MESAW retentions at 117 watershed resolution. All retentions reported as percentages (%).

Drainage Basin ID	groundwater N retentions (%) Cattle	Pigs	Catch
DE-BP	61	61	61
DE-DS	76	76	76
DK-BP	12	19	8
DK-DS	73	70	69
DK-KT	55	56	57
EE-BP	0	0	0
EE-GF	1	1	1
EE-GR	15	15	17
FI-BB	28	42	43
FI-BS	16	17	19
FI-GF	22	26	32
LT-BP	56	56	56
LV-BP	19	19	19
LV-GR	2	2	4
PL-BP	70	71	70
RU-BP	88	92	79
RU-GF	33	33	33
SE-BB	11	12	13
SE-BP	37	39	48
SE-BS	31	41	45
SE-DS	33	33	33
SE-KT	7	8	7

Table 10: Area-weighted or numbers-weighted surface water N retentions for the cattle reduction (cattle), pig reduction (pigs), catch crops (catch), wetlands and WWT N abatement measures in the 22 Drainage Basins, derived from MESAW retentions at 117 watershed resolution. All retentions reported as percentages (%).

Drainage Basin ID	surface water N retentions (%)				
	Cattle	Pigs	Catch	Wetlands	WWT
DE-BP	20	20	20	21	18
DE-DS	29	29	29	29	29
DK-BP	3	3	3	2	2
DK-DS	13	12	10	10	14
DK-KT	14	13	13	13	11
EE-BP	10	10	9	11	11
EE-GF	9	9	9	7	7
EE-GR	7	7	7	6	7
FI-BB	36	29	23	26	32
FI-BS	41	40	38	37	37
FI-GF	57	51	39	60	50
LT-BP	30	30	30	30	30
LV-BP	16	16	16	16	16
LV-GR	20	19	18	20	18
PL-BP	31	30	30	30	31
RU-BP	46	47	46	47	47
RU-GF	35	35	42	42	32
SE-BB	37	37	39	36	36
SE-BP	48	48	50	54	48
SE-BS	39	39	39	38	39
SE-DS	9	9	9	9	9
SE-KT	48	46	50	50	46

Table 10: Area-weighted or numbers-weighted surface water P retentions for the cattle reduction (cattle), pig reduction (pigs), wetlands and WWT P abatement measures in the 22 Drainage Basins, derived from MESAW retentions at 117 watershed resolution. All retentions reported as percentages (%).

Drainage Basin ID	surface water P retentions (%) Cattle	Pigs	Wetlands	WWT
DE-BP	11	11	11	11
DE-DS	14	14	14	14
DK-BP	7	7	7	7
DK-DS	10	10	9	11
DK-KT	10	10	10	9
EE-BP	9	9	10	10
EE-GF	9	9	8	8
EE-GR	12	12	12	12
FI-BB	23	17	17	18
FI-BS	22	22	21	20
FI-GF	29	26	31	26
LT-BP	40	40	40	39
LV-BP	17	17	13	17
LV-GR	33	33	34	30
PL-BP	45	43	42	44
RU-BP	14	14	13	14
RU-GF	43	43	47	45
SE-BB	26	27	26	24
SE-BP	21	21	24	22
SE-BS	24	22	21	22
SE-DS	9	9	9	9
SE-KT	28	27	30	26

Annex 2. Decriptions of measures and cost functions.

- Annex 2.1. Reductions in fertiliser applications to arable crops (N abatement)
- Annex 2.2. Catch crops under spring-sown cereals (N abatement)
- Annex 2.3. Reductions in livestock numbers (N & P abatement)
- Annex 2.4. Restoring wetlands on agricultural soils (N & P abatement)
- Annex 2.5. Improving wastewater treatment (WWT) (N & P abatement)
- Annex 2.6. NOx reductions from power plants and ships (not implemented in BALTCOST version 8.0)

Annex 2.1. . Reductions in fertiliser applications to arable crops (N abatement)

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This annex describes how nitrogen fertiliser reduction costs are portrayed in the BALTCOST model for identifying the lowest cost combination of abatement measures for delivering specified reduction targets for nitrogen (N) and phosphorus (P) loads into 7 sea regions of the Baltic Sea. The reductions of nitrogen fertilisers to agricultural crops is one of 6 abatement measures considered by BALTCOST.

The description of the fertiliser reduction measure in BALTCOST proceeds in the following sequence:

- the fertiliser reduction measure
- methodology for estimating the cost function
- data sources used in estimating the cost function
- effects of fertiliser reductions N loads into the river systems and thence into the receiving sea regions in the Baltic
- capacity for implementing fertiliser reductions

2.1.1. Reductions of nitrogen fertilisers as a measure to reduce loads

Reduction of nitrogen fertilisers is an effective measure to reduce nitrogen loads, fertilisers to agricultural crops, and includes both reduction in the application of commercial fertilisers and nitrogen in animal manure. The manure N is calculated as the effective N applied to the crops, where it is anticipated that 70% of the N applied is utilised and hereby replace commercial fertiliser N in Denmark and Sweden. In the other countries (Germany, Finland, Russia, Latvia, Lithuania, Estonia and Poland) the utilisation rate is lower, and the assumption is 50% (REF). The difference is explained by the difference in application methods, timing,manure storage and handling systems, as well as the type of livestock produced.

It is assumed that fertiliser applications can be reduced at both arable land and crops grown outside rotation, but for some crops it is very difficult to get a reliable estimate of the initial level of nitrogen fertiliser application, e.g. permanent grass which has a large variation in N levels inside a country because the terminology “permanent grasslands” covers a large range of different productions systems. We have described the assumptions made in the end of this annex.

2.1.2. Methodology for the cost calculations

The fundamental equations in the cost calculations for fertiliser reductions are the crop and drainage basin specific yield functions that describe the dose-response relationship between nitrogen fertiliser and crop yield. The point of departure for the functions is Danish experimental functions taken from Pedersen (2009). The Danish functions are adapted to the other drainage basins by a calibration procedure described by Brady (2002). The calibration procedure and the applied data material are described in the section 2.1.3. 'Calibration methodology' and 2.1.4. Data. After calibration the dose-response relationship between fertiliser and crop yield in each country is formalised in a second order polynomial of the form:

$$y_{c,I}(N_{c,I}) = \alpha_{c,I} + \beta_{c,I} N_{c,I} + \gamma_{c,I} N_{c,I}^2$$

where y is crop yield in 100 kg per hectare, N is nitrogen fertilisation in kg per hectare and α, β and γ are parameters of the function specific for country I and crop c. An example of a yield function is illustrated in figure 1. The top point of the yield function is not economically optimal even though it is the maximum attainable yield as no prices of inputs and outputs are taken into account. The flatter the slope of the function the less extra yield will be produced by increasing fertilisation, so as the fertilisation approaches the maximum yield the marginal return to fertilisation will diminish.

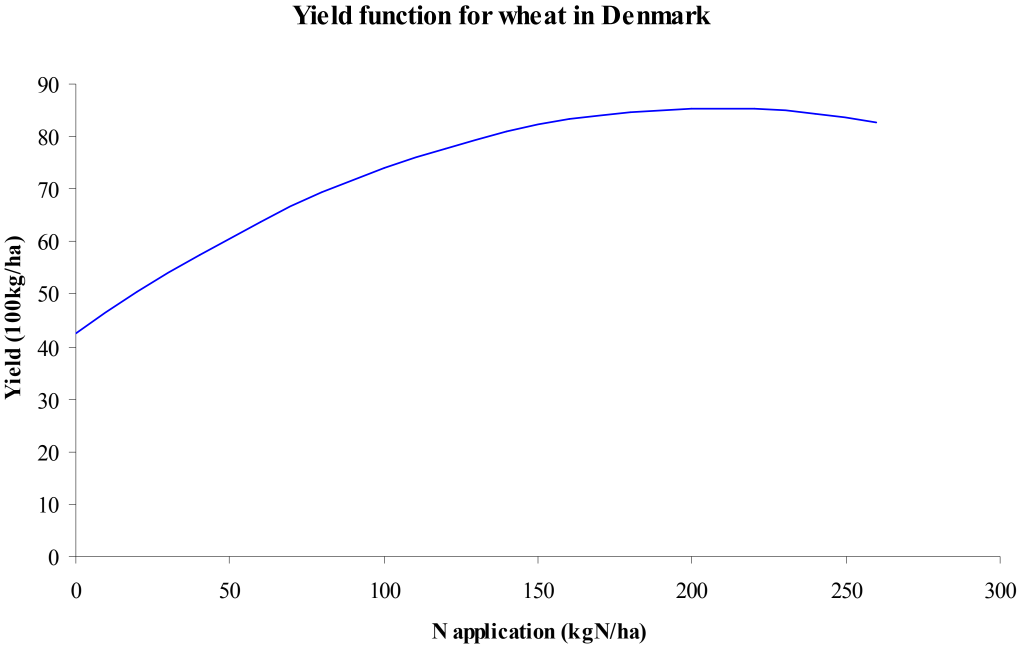

Figure 1 Yield function for wheat in Denmark. Crop yield is dependant on the concentration of the fertiliser application

The parameters of the yield functions are reported in table 1, 2 and 3 for all crops in alle drainage basins.

α parameters

	BARL	FALL	GRAE	GRAI	MAIF	OATS	OFAO	OFAR	POTA	PULS	RAPE	RYEM	SUGB	SWHE
DE_BP	41.256	0.000	26.546	26.546	165.737	35.044	35.723	26.546	389.086	0.000	16.421	34.101	104.380	37.739
DE_DS	41.256	0.000	26.546	26.546	165.737	35.044	35.723	26.546	389.086	0.000	16.421	34.101	104.380	37.739
DK_BP	34.920	0.000	46.461	46.461	138.960	31.469	62.523	46.461	362.890	0.000	24.748	32.103	98.714	42.489
DK_DS	34.920	0.000	46.461	46.461	138.960	31.469	62.523	46.461	362.890	0.000	24.748	32.103	98.714	42.489
DK_KT	34.920	0.000	46.461	46.461	138.960	31.469	62.523	46.461	362.890	0.000	24.748	32.103	98.714	42.489
EE_BP	16.828	0.000	37.734	37.734	80.658	16.730	50.778	37.734	140.152	0.000	8.125	15.862	64.398	16.485
EE_GF	16.828	0.000	37.734	37.734	80.658	16.730	50.778	37.734	140.152	0.000	8.125	15.862	64.398	16.485
EE_GR	16.828	0.000	37.734	37.734	80.658	16.730	50.778	37.734	140.152	0.000	8.125	15.862	64.398	16.485
FI_BB	24.282	0.000	43.208	43.208	138.960	21.413	58.145	43.208	232.268	0.000	15.198	17.949	62.975	24.161
FI_BS	24.282	0.000	43.208	43.208	138.960	21.413	58.145	43.208	232.268	0.000	15.198	17.949	62.975	24.161
FI_GF	24.282	0.000	43.208	43.208	138.960	21.413	58.145	43.208	232.268	0.000	15.198	17.949	62.975	24.161
LT_BP	19.930	0.000	42.511	42.511	94.928	13.997	57.208	42.511	123.241	0.000	10.943	16.717	71.523	25.677
LV_BP	15.055	0.000	38.241	38.241	84.565	12.396	51.461	38.241	142.820	0.000	10.460	13.481	64.398	19.141
LV_GR	15.055	0.000	38.241	38.241	84.565	12.396	51.461	38.241	142.820	0.000	10.460	13.481	64.398	19.141
PL_BP	19.638	0.000	46.273	46.273	158.001	13.995	62.271	46.273	175.081	0.000	11.159	13.310	78.929	21.724
RU_BP	13.861	0.000	5.046	5.046	54.181	12.071	6.790	5.046	105.307	0.000	10.585	14.377	39.961	13.262
RU_GF	13.861	0.000	5.046	5.046	54.181	12.071	6.790	5.046	105.307	0.000	10.585	14.377	39.961	13.262
SE_BB	24.542	0.000	14.338	14.338	138.960	22.484	19.294	14.338	280.552	0.000	15.559	32.591	88.116	29.690
SE_BP	24.542	0.000	14.338	14.338	138.960	22.484	19.294	14.338	280.552	0.000	15.559	32.591	88.116	29.690
SE_BS	24.542	0.000	14.338	14.338	138.960	22.484	19.294	14.338	280.552	0.000	15.559	32.591	88.116	29.690
SE_DS	24.542	0.000	14.338	14.338	138.960	22.484	19.294	14.338	280.552	0.000	15.559	32.591	88.116	29.690
SE_KT	24.542	0.000	14.338	14.338	138.960	22.484	19.294	14.338	280.552	0.000	15.559	32.591	88.116	29.690

Table 1 α parameters for the yield functions

β parameters

	BARL	FALL	GRAE	GRAI	MAIF	OATS	OFAO	OFAR	POTA	PULS	RAPE	RYEM	SUGB	SWHE
DE_BP	0.2417	0.0000	0.6119	0.6119	0.0971	0.3218	0.1754	0.6119	1.4861	0.0000	0.1202	0.2679	0.5878	0.3713
DE_DS	0.2417	0.0000	0.6119	0.6119	0.0971	0.3218	0.1754	0.6119	1.4861	0.0000	0.1202	0.2679	0.5878	0.3713
DK_BP	0.2794	0.0000	0.6119	0.6119	0.0971	0.3298	0.1754	0.6119	1.4861	0.0000	0.1704	0.3306	0.5878	0.4149
DK_DS	0.2794	0.0000	0.6119	0.6119	0.0971	0.3298	0.1754	0.6119	1.4861	0.0000	0.1704	0.3306	0.5878	0.4149
DK_KT	0.2794	0.0000	0.6119	0.6119	0.0971	0.3298	0.1754	0.6119	1.4861	0.0000	0.1704	0.3306	0.5878	0.4149
EE_BP	0.1051	0.0000	0.6119	0.6119	0.0971	0.1400	0.1754	0.6119	1.4861	0.0000	0.0588	0.1123	0.5878	0.1035
EE_GF	0.1051	0.0000	0.6119	0.6119	0.0971	0.1400	0.1754	0.6119	1.4861	0.0000	0.0588	0.1123	0.5878	0.1035
EE_GR	0.1051	0.0000	0.6119	0.6119	0.0971	0.1400	0.1754	0.6119	1.4861	0.0000	0.0588	0.1123	0.5878	0.1035
FI_BB	0.1810	0.0000	0.6119	0.6119	0.0971	0.2339	0.1754	0.6119	1.4861	0.0000	0.0806	0.1260	0.5878	0.1763
FI_BS	0.1810	0.0000	0.6119	0.6119	0.0971	0.2339	0.1754	0.6119	1.4861	0.0000	0.0806	0.1260	0.5878	0.1763
FI_GF	0.1810	0.0000	0.6119	0.6119	0.0971	0.2339	0.1754	0.6119	1.4861	0.0000	0.0806	0.1260	0.5878	0.1763
LT_BP	0.1077	0.0000	0.6119	0.6119	0.0971	0.1230	0.1754	0.6119	1.4861	0.0000	0.0566	0.1243	0.5878	0.1443
LV_BP	0.1063	0.0000	0.6119	0.6119	0.0971	0.1277	0.1754	0.6119	1.4861	0.0000	0.0601	0.1224	0.5878	0.1335
LV_GR	0.1063	0.0000	0.6119	0.6119	0.0971	0.1277	0.1754	0.6119	1.4861	0.0000	0.0601	0.1224	0.5878	0.1335
PL_BP	0.1215	0.0000	0.6119	0.6119	0.0971	0.1270	0.1754	0.6119	1.4861	0.0000	0.0921	0.1139	0.5878	0.1569
RU_BP	0.1190	0.0000	0.6119	0.6119	0.0971	0.1358	0.1754	0.6119	1.4861	0.0000	0.0600	0.1505	0.5878	0.1323
RU_GF	0.1190	0.0000	0.6119	0.6119	0.0971	0.1358	0.1754	0.6119	1.4861	0.0000	0.0600	0.1505	0.5878	0.1323
SE_BB	0.2287	0.0000	0.6119	0.6119	0.0971	0.2789	0.1754	0.6119	1.4861	0.0000	0.1253	0.3027	0.5878	0.3090
SE_BP	0.2287	0.0000	0.6119	0.6119	0.0971	0.2789	0.1754	0.6119	1.4861	0.0000	0.1253	0.3027	0.5878	0.3090
SE_BS	0.2287	0.0000	0.6119	0.6119	0.0971	0.2789	0.1754	0.6119	1.4861	0.0000	0.1253	0.3027	0.5878	0.3090
SE_DS	0.2287	0.0000	0.6119	0.6119	0.0971	0.2789	0.1754	0.6119	1.4861	0.0000	0.1253	0.3027	0.5878	0.3090
SE_KT	0.2287	0.0000	0.6119	0.6119	0.0971	0.2789	0.1754	0.6119	1.4861	0.0000	0.1253	0.3027	0.5878	0.3090

Table 2 β parameters for the yield functions

	γ parameters													
	BARL	FALL	GRAE	GRAI	MAIF	OATS	OFAO	OFAR	POTA	PULS	RAPE	RYEM	SUGB	SWHE
DE_BP	-0.0011	0.0000	-0.0009	-0.0009	-0.0002	-0.0014	-0.0002	-0.0009	-0.0029	0.0000	-0.0003	-0.0010	-0.0025	-0.0009
DE_DS	-0.0011	0.0000	-0.0009	-0.0009	-0.0002	-0.0014	-0.0002	-0.0009	-0.0029	0.0000	-0.0003	-0.0010	-0.0025	-0.0009
DK_BP	-0.0009	0.0000	-0.0009	-0.0009	-0.0002	-0.0013	-0.0002	-0.0009	-0.0029	0.0000	-0.0004	-0.0009	-0.0025	-0.0010
DK_DS	-0.0009	0.0000	-0.0009	-0.0009	-0.0002	-0.0013	-0.0002	-0.0009	-0.0029	0.0000	-0.0004	-0.0009	-0.0025	-0.0010
DK_KT	-0.0009	0.0000	-0.0009	-0.0009	-0.0002	-0.0013	-0.0002	-0.0009	-0.0029	0.0000	-0.0004	-0.0009	-0.0025	-0.0010
EE_BP	-0.0004	0.0000	-0.0009	-0.0009	-0.0002	-0.0007	-0.0002	-0.0009	-0.0029	0.0000	-0.0001	-0.0004	-0.0025	-0.0004
EE_GF	-0.0004	0.0000	-0.0009	-0.0009	-0.0002	-0.0007	-0.0002	-0.0009	-0.0029	0.0000	-0.0001	-0.0004	-0.0025	-0.0004
EE_GR	-0.0004	0.0000	-0.0009	-0.0009	-0.0002	-0.0007	-0.0002	-0.0009	-0.0029	0.0000	-0.0001	-0.0004	-0.0025	-0.0004
FI_BB	-0.0006	0.0000	-0.0009	-0.0009	-0.0002	-0.0009	-0.0002	-0.0009	-0.0029	0.0000	-0.0002	-0.0005	-0.0025	-0.0006
FI_BS	-0.0006	0.0000	-0.0009	-0.0009	-0.0002	-0.0009	-0.0002	-0.0009	-0.0029	0.0000	-0.0002	-0.0005	-0.0025	-0.0006
FI_GF	-0.0006	0.0000	-0.0009	-0.0009	-0.0002	-0.0009	-0.0002	-0.0009	-0.0029	0.0000	-0.0002	-0.0005	-0.0025	-0.0006
LT_BP	-0.0005	0.0000	-0.0009	-0.0009	-0.0002	-0.0006	-0.0002	-0.0009	-0.0029	0.0000	-0.0002	-0.0005	-0.0025	-0.0006
LV_BP	-0.0004	0.0000	-0.0009	-0.0009	-0.0002	-0.0005	-0.0002	-0.0009	-0.0029	0.0000	-0.0002	-0.0004	-0.0025	-0.0005
LV_GR	-0.0004	0.0000	-0.0009	-0.0009	-0.0002	-0.0005	-0.0002	-0.0009	-0.0029	0.0000	-0.0002	-0.0004	-0.0025	-0.0005
PL_BP	-0.0005	0.0000	-0.0009	-0.0009	-0.0002	-0.0006	-0.0002	-0.0009	-0.0029	0.0000	-0.0002	-0.0004	-0.0025	-0.0005
RU_BP	-0.0004	0.0000	-0.0009	-0.0009	-0.0002	-0.0005	-0.0002	-0.0009	-0.0029	0.0000	-0.0002	-0.0004	-0.0025	-0.0003
RU_GF	-0.0004	0.0000	-0.0009	-0.0009	-0.0002	-0.0005	-0.0002	-0.0009	-0.0029	0.0000	-0.0002	-0.0004	-0.0025	-0.0003
SE_BB	-0.0006	0.0000	-0.0009	-0.0009	-0.0002	-0.0009	-0.0002	-0.0009	-0.0029	0.0000	-0.0003	-0.0009	-0.0025	-0.0007
SE_BP	-0.0006	0.0000	-0.0009	-0.0009	-0.0002	-0.0009	-0.0002	-0.0009	-0.0029	0.0000	-0.0003	-0.0009	-0.0025	-0.0007
SE_BS	-0.0006	0.0000	-0.0009	-0.0009	-0.0002	-0.0009	-0.0002	-0.0009	-0.0029	0.0000	-0.0003	-0.0009	-0.0025	-0.0007
SE_DS	-0.0006	0.0000	-0.0009	-0.0009	-0.0002	-0.0009	-0.0002	-0.0009	-0.0029	0.0000	-0.0003	-0.0009	-0.0025	-0.0007
SE_KT	-0.0006	0.0000	-0.0009	-0.0009	-0.0002	-0.0009	-0.0002	-0.0009	-0.0029	0.0000	-0.0003	-0.0009	-0.0025	-0.0007

Table 3 γ parameters for the yield functions

From the yield functions a profit function for each crop can be constructed as

$$\pi_{c,I}(N_{c,I}) = A_{c;I}(p_{c,I}y_{c,I}(N_{c,I}) - n_I N_{c,I})$$

where $p_{c,I}$ is the price of 100 kg of output of crop *c* in contry *I*, n_I is the price of nitrogen fertiliser in country *I* and $A_{c,I}$ is the number of hectares sown with crop *c* in contry *I*. Data on prices of crop outputs and fertiliser inputs are obtained from Eurostat and the areas of each crop in each country and drainage basin are provided by Hans Estrup Andersen (Andersen et al 2011). A reduction in the level of fertilisation can thus be calculated as the difference between the profit from the reduced fertiliser application and the profit at the initial fertiliser application. For each country and crop this cost is thus calculated as:

$$\Delta\pi_{c,I}(N_{c,I}) = \pi_{c,I}(N^*_{c,I}) - \pi_{c,I}(N_{c,I})$$

where $\pi_{c,I}(N^*)$ is the profit at the initial level of fertilisation and $\pi_{c,I}(N)$ is the profit at the reduced level for crop *c* in country *I*. The costs of reduction are thus calculated as the difference in profit which takes into account the foregone yield and the savings on fertiliser by reducing fertilisation from N^* to *N*. The prices of crop output in each drainage basin are reported in table 4 and the prices of nitrogen fertiliser are reported in table 5.

Prices of crop output (€/100 kg)

	BARL	FALL	GRAE	GRAI	MAIF	OATS	OFAO	OFAR	POTA	PULS	RAPE	RYEM	SUGB	SWHE
DE_BP	11.04	0.00	8.96	8.96	3.84	10.02	8.96	8.96	10.19	3.84	21.66	9.66	4.70	10.78
DE_DS	11.04	0.00	8.96	8.96	3.84	10.02	8.96	8.96	10.19	3.84	21.66	9.66	4.70	10.78
DK_BP	11.04	0.00	14.81	14.81	3.84	10.42	14.81	14.81	18.97	3.84	21.86	9.66	4.70	11.26
DK_DS	11.04	0.00	14.81	14.81	3.84	10.42	14.81	14.81	18.97	3.84	21.86	9.66	4.70	11.26
DK_KT	11.04	0.00	14.81	14.81	3.84	10.42	14.81	14.81	18.97	3.84	21.86	9.66	4.70	11.26
EE_BP	9.88	0.00	4.23	4.23	1.76	8.61	4.23	4.23	15.40	1.76	23.23	10.35	4.22	10.71
EE_GF	9.88	0.00	4.23	4.23	1.76	8.61	4.23	4.23	15.40	1.76	23.23	10.35	4.22	10.71
EE_GR	9.88	0.00	4.23	4.23	1.76	8.61	4.23	4.23	15.40	1.76	23.23	10.35	4.22	10.71
FI_BB	10.27	0.00	14.56	14.56	2.19	9.39	14.56	14.56	19.13	2.19	22.30	12.64	4.56	11.22
FI_BS	10.27	0.00	14.56	14.56	2.19	9.39	14.56	14.56	19.13	2.19	22.30	12.64	4.56	11.22
FI_GF	10.27	0.00	14.56	14.56	2.19	9.39	14.56	14.56	19.13	2.19	22.30	12.64	4.56	11.22
LT_BP	9.92	0.00	1.38	1.38	1.14	7.79	1.38	1.38	15.40	1.14	20.54	9.41	4.22	10.94
LV_BP	9.04	0.00	2.92	2.92	1.59	7.98	2.92	2.92	9.27	1.59	20.55	8.77	4.24	10.08
LV_GR	9.04	0.00	2.92	2.92	1.59	7.98	2.92	2.92	9.27	1.59	20.55	8.77	4.24	10.08
PL_BP	10.14	0.00	8.36	8.36	1.39	8.17	8.36	8.36	9.23	1.39	20.77	8.18	3.93	10.34
RU_BP	7.27	0.00	1.38	1.38	1.14	7.06	1.38	1.38	14.86	1.14	20.54	6.66	2.74	7.12
RU_GF	7.27	0.00	1.38	1.38	1.14	7.06	1.38	1.38	14.86	1.14	20.54	6.66	2.74	7.12
SE_BB	9.76	0.00	12.49	12.49	4.38	9.41	12.49	12.49	20.06	4.38	22.02	10.11	3.92	10.54
SE_BP	9.76	0.00	12.49	12.49	4.38	9.41	12.49	12.49	20.06	4.38	22.02	10.11	3.92	10.54
SE_BS	9.76	0.00	12.49	12.49	4.38	9.41	12.49	12.49	20.06	4.38	22.02	10.11	3.92	10.54
SE_DS	9.76	0.00	12.49	12.49	4.38	9.41	12.49	12.49	20.06	4.38	22.02	10.11	3.92	10.54
SE_KT	9.76	0.00	12.49	12.49	4.38	9.41	12.49	12.49	20.06	4.38	22.02	10.11	3.92	10.54

Table 4 Prices of crop output in € per 100 kg

Prices of fertiliser (€/kg)	
DE_BP	0.56
DE_DS	0.56
DK_BP	0.84
DK_DS	0.84
DK_KT	0.84
EE_BP	0.61
EE_GF	0.61
EE_GR	0.61
FI_BB	0.7
FI_BS	0.7
FI_GF	0.7
LT_BP	0.51
LV_BP	0.61
LV_GR	0.61
PL_BP	0.565
RU_BP	0.6
RU_GF	0.6
SE_BB	1.12
SE_BP	1.12
SE_BS	1.12
SE_DS	1.12
SE_KT	1.12

Table 5 Prices of fertiliser in € per kg

The initial level of fertilisation is assumed to be the economically optimal fertilisation in terms of the constructed profit functions. This assumption sets the initial fertilisation to the top point of the profit polynomial which is determined by the relative country specific prices of the nitrogen input and the crop output and the slope and curvature of the country specific yield function. The economically optimal fertilisation N^{OPT} can be determined by:

$$\frac{\partial \pi(N_{c,I})}{\partial N_{c,I}} = A_{c,I}(p_{c,I}(\alpha_{c,I} + \beta_{c,I}N_{c,I} + 2\gamma_{c,I}N_{c,I}) - n_I N_{c,I}) = 0$$

$$\Leftrightarrow p_{c,I}(\alpha_{c,I} + \beta_{c,I}N_{c,I} + 2\gamma_{c,I}N_{c,I}) - n_I N_{c,I} = 0$$

$$\Leftrightarrow N_{c,I}^{OPT} = \frac{\frac{n_I}{p_{c,I}} - \beta_{c,I}}{2\gamma_{c,I}}$$

The optimal level of fertilisation is illustrated in figure 2 along with a reduction in fertilisation and the associated cost. The corresponding cost function is illustrated in figure 3.

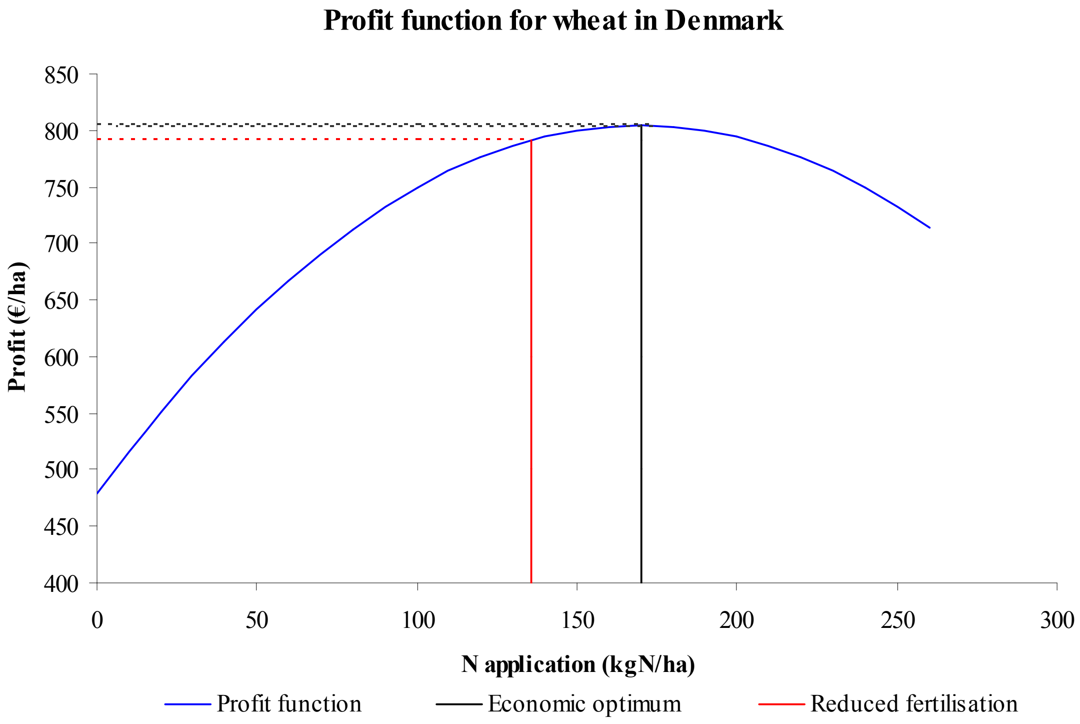

Figure 2 The black vertical line is the economic optimum. The red vertical line is a new reduced fertiliser application. The area between the two dotted lines is the cost of the reduction.

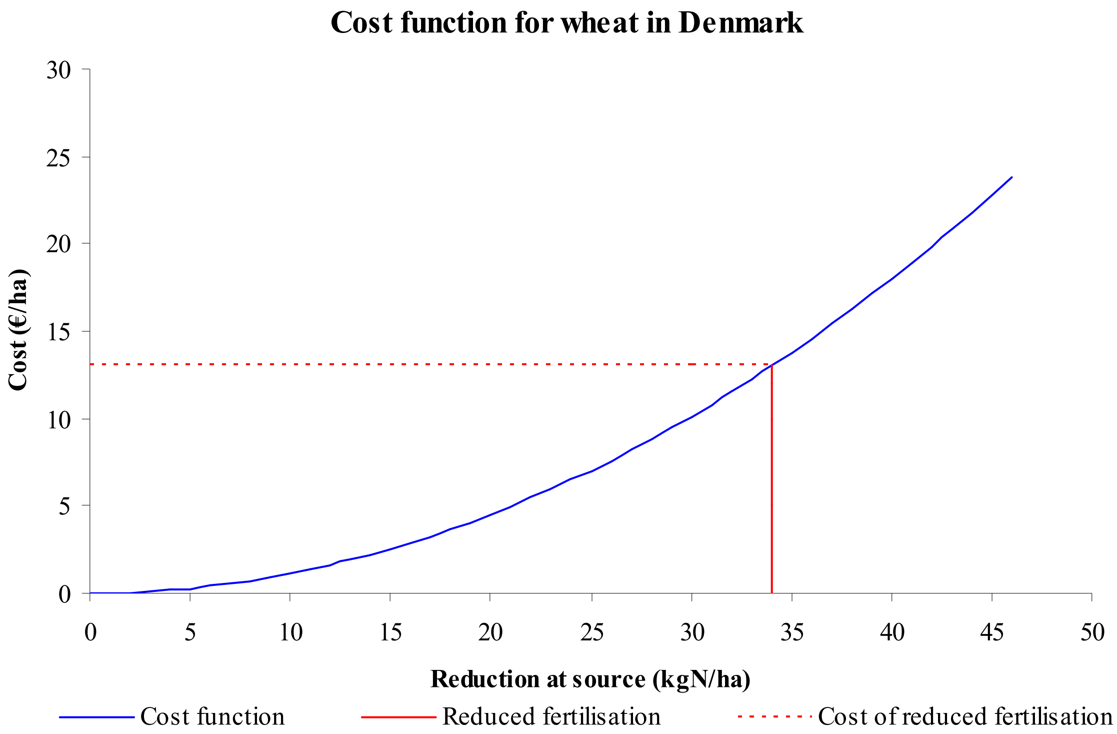

Figure 3 Cost function for fertiliser reductions. The red line corresponds to the reduction illustrated in figure 2

The cost of a given fertiliser reduction is thus determined by the prices of crop output and fertiliser input and yield functions of the crops in the countries. Any reduction of fertilisation below the economic optimum will be associated with a cost and this cost will increase exponentially in reductions.

2.1.3. Calibration methology

Yield functions for all the countries in the model are not available. Therefore the relationship between nitrogen usage and yield is not established for all regions that are emitting nitrogen to the Baltic. This lack of data has the unfortunate consequence that the potential yield loss corresponding to a reduction in fertilisation is not identifiable for all countries. In order to obtain nitrogen response functions for all countries we apply experimental yield functions from Danish crop experiments (Pedersen, 2009) and employ the methodology of Brady(2002) to calibrate the experimental functions to the remaining countries.

The experimental data is from Pedersen(2009) is in an initial step used to estimate second order polynomial nitrogen response functions. These functions thus have the form given in (1)

$$Y = \alpha + \beta N + \gamma N^2 \qquad (1)$$

Where α, β and γ are the estimated parameters of the yield function, Y is the yield in hkg/ha and N is the applied concentration of nitrogen in kg/ha.

According to Brady(2002) the calibrated yield function for country j is given by (2)

$$Y_j = \theta_j(\alpha + \delta_j \beta N_j + \gamma N_j^2) \tag{2}$$

Where the calibration parameter θ_j determines the change in the experimental yield function caused by the productivity in country j (changing the level of the curve) and δ_j is the adjustment parameter for diffences in nitrogen productivity (changing the curvature). The profit function for a specific crop in country j is thus given by (3)

$$\pi_j = p_{c,j}\theta_j(\alpha + \delta_j \beta N_j + \gamma N_j^2) - p_{N,j} N_j \tag{3}$$

Where $p_{c,j}$ is the price per hkg of the crop in country j and $p_{N,j}$ is the price of a kg of nitrogen.

We assume that the farmers are exhibit profit maximising behaviour in the sense that they will apply nitrogen until the extra yield obtained by one more unit of nitrogen equals the relative price of nitrogen and the given crop. That is:

$$\theta_j(\delta_j \beta + 2\gamma N_j) = \frac{p_{N,j}}{p_{c,j}} \tag{4}$$

By solving for θ_j and substituting into (2) we can thus rearrange to obtain an expression for δ_j which is presented in (5)

$$\delta_j = \frac{p_{N,j}(\alpha + \gamma N^2) - 2Yp_{c,j}\gamma N}{\beta(Yp_{c,j} - p_{N,j}N)} \tag{5}$$

Given the expression for δ_j in (5) , (2) can be rearranged to give the expression for θ_j presented in (6)

$$\theta_j = \frac{Y}{\alpha + \delta_j \beta N + \gamma N^2} \tag{6}$$

We thus have two equations in two unknowns. If we then employ the average yield for each country ($Y = \overline{Y}$) and the average nitrogen usage ($N = \overline{N}$) to this system, δ_j is identified purely by the known parameters of the experimental functions (α, β and γ), the known prices $p_{N,j}$ and $p_{c,j}$ and the average yield and nitrogen usage. Identification of δ_j further allow us to calculate θ_j by substituting the known parameters into (6). By assuming the farmers on average exhibit profit maximising behaviour we can thus obtain the parameters θ_j and δ_j. Given these parameters and expression (2) the yield function of country j can thus be obtained by (7)

$$Y_j = \alpha_j + \beta_j N_j + \gamma_j N_j^2 \tag{7}$$

Where $\alpha_j=\theta_j\alpha$, $\beta_j=\theta_j\delta_j\beta$ and $\gamma_j=\theta_j\gamma$. By calibrating the experimental functions of Pedersen(2009) by the prices of crops and nitrogen respectively and the average yields and nitrogen usages we can thus obtain yield functions for the other countries in the region.

2.1.4. Data

The point of departure of the calibration is -as mentioned above- the experimental nitrogen response functions of Pedersen(2009). From the experiments we have functions for the following crops: Wheat, barley, rye, oats, rape, sugar beets, potatoes, maize, clover grass and temporary grass. For calibration of these functions to the other countries around

the Baltic the needed data is: prices of the crops in question, the price of nitrogen fertiliser, the average yield and the average nitrogen input for all countries.
Prices of yield per 100 kg of crops are taken from Eurostats table of selling prices of crop products and are based on the selling prices from 2004 to 2006. Selling prices from Russia and Belarus are not available in Eurostat. Russian prices are obtained from the Russian Agricultural Yearbook for 2005 and these prices are used for Belarus as well as an approximation. A missing price of barley for Germany is replaced with the Danish price.

Average yields for each country is obtained from Eurostat and nitrogen usages are obtained from Ministry of Food, Agriculture and Fishery (1999) for Denmark, Statistics Sweden (2002) for Sweden and for the rest of the countries nitrogen usage is estimated (Andersen et al 2011). For Belarus yields and nitrogen usage are taken from Poleschyk(2010). The yield and fertiliser data from Belarus is used as an approximation for Russia as well.

Prices of fertiliser are taken from Eurostats table of purchase prices of the means of agricultural production and are based on the average price of 100 kg N (in ammonium nitrate 26%, aminium nitrate 34% and urea 46%). These data are subsequently corrected for Poland and Sweden based on data from the Polish Central Statistical Office and the Swedish Agricultural Statistics Yearbook (Statistics Sweden, 2006). The Eurostat database does not contain a price of nitrogen for Estonia so the price from Latvia is used as an approximation.

Some of the crops in the model are primarily used as fodder crops. For this reason they do not have recorded selling prices that can be used for the calibration. An approximation of the price is therefore derived from the standard outputs that denote the value of the production. Standard outputs for maize and grass is taken from the Eurostat table of value of production. The value of production is recalculated from €/ha by dividing by the average yield per ha (hkg/ha) which yields a value per hkg. This value is subsequently used to perform a calibration similar to the crops for which selling prices are available. Data on the yields of maize and grass are not available for all countries. For this reason the yield from Denmark serves as approximation for Germany, Estonias yield for maize is approximated by the Latvian yield and the Latvian yield for grass is approximated by the Estonian yield. The Finnish and Swedish yields for both crops is approximated by the average of the Danish and Polish yields. For Russia and Belarus neither standard output, yield nor fertilisation are available. Therefore these functions are approximated by the Lithuanian functions.

2.1.5. Effects of fertiliser reductions on nitrogen leaching and loads

The above framework describes the cost calculations of fertiliser reduction. From these functions costs can be determined for a given reduction on crop c in country I. However a reduction in fertiliser application on the fields of country c does not result in the same reduction in nitrogen loads to the Baltic Sea. The fertiliser reduced on the fields goes through a series of processes before it leads to effective reduction in the Baltic. The first step to consider is the amount of nitrogen fertiliser leaching from the root zone on the arable lands. The relationship between nitrogen application and nitrogen leaching has been described by Hans Estrup Andersen (Andersen et al 2011) and formalised in a leaching function of the form:

$$L_{c,I}(N_{c,I}) = K_{c,I}(N_{c,I} + N_{c,I}^{S})^{B_{c,I}}$$

where $L_{c,I}$ is the amount of nitrogen leached from the root zone of crop *c* in country *I*, $K_{c,I}$ and $B_{c,I}$ are parameters of the function, $N_{c,I}$ is the applied amount of nitrogen fertiliser, $N_{c,I}{}^{S}$ is the nitrogen from seeds and fixation. The effectiveness of a fertiliser reduction is thus determined by the country and crop specific leaching $L_{c,I}$ associated with the reduction in $N_{c,I}$. The nitrogen from seeds and fixation ($N_{c,I}{}^{S}$) is considered fixed as this is not a parameter that is controlled by farmers and thus reductions are not possible for these types of nitrogen input. The parameters of the leaching functions for each crop and drainage basin are reported in table 6, 7 and 8.

Leaching function K parameters

	BARL	FALL	GRAE	GRAI	MAIF	OATS	OFAO	OFAR	POTA	PULS	RAPE	RYEM	SUGB	SWHE
DE_BP	0.747	0.764	0.210	0.037	0.116	3.671	0.268	0.032	0.159	43.178	0.749	0.406	0.006	0.173
DE_DS	0.744	0.832	0.198	0.037	0.114	3.670	0.273	0.032	0.163	44.097	0.742	0.415	0.006	0.173
DK_BP	0.691	0.714	0.151	0.033	0.127	3.789	0.267	0.030	0.148	40.366	0.716	0.390	0.004	0.162
DK_DS	0.721	0.715	0.170	0.035	0.125	3.672	0.271	0.032	0.161	42.495	0.745	0.405	0.006	0.170
DK_KT	1.229	2.599	0.129	0.047	0.188	5.502	0.438	0.040	0.140	65.752	1.090	0.621	0.007	0.222
EE_BP	0.725	0.000	0.000	0.035	0.000	3.703	0.000	0.032	0.160	42.653	0.732	0.405	0.000	0.171
EE_GF	0.716	0.000	0.000	0.035	0.000	3.536	0.000	0.032	0.166	42.998	0.719	0.402	0.000	0.170
EE_GR	0.745	0.000	0.000	0.036	0.177	3.738	0.000	0.032	0.166	43.750	0.751	0.416	0.009	0.175
FI_BB	1.181	2.625	0.220	0.041	0.000	4.661	0.396	0.037	0.146	58.216	0.992	0.587	0.006	0.201
FI_BS	1.073	2.320	0.135	0.046	0.124	4.770	0.393	0.037	0.144	54.232	0.950	0.523	0.006	0.174
FI_GF	1.245	2.894	0.152	0.047	0.161	5.113	0.450	0.039	0.141	62.083	1.053	0.592	0.007	0.212
LT_BP	1.003	0.000	0.000	0.042	0.135	5.281	0.000	0.037	0.138	56.764	0.901	0.554	0.008	0.191
LV_BP	0.782	0.000	0.000	0.036	0.114	3.679	0.000	0.031	0.149	45.479	0.759	0.421	0.006	0.171
LV_GR	0.851	0.000	0.000	0.035	0.117	4.505	0.000	0.034	0.147	53.897	0.811	0.488	0.006	0.175
PL_BP	0.866	1.330	0.140	0.038	0.133	4.055	0.334	0.035	0.143	48.287	0.832	0.467	0.006	0.180
RU_BP	1.040	0.000	0.000	0.043	0.124	4.670	0.000	0.039	0.140	55.183	0.878	0.525	0.008	0.188
RU_GF	1.069	3.241	0.138	0.038	0.101	5.148	0.466	0.037	0.153	59.201	0.815	0.546	0.008	0.197
SE_BB	1.498	3.856	0.165	0.048	0.000	5.715	0.487	0.041	0.134	62.980	0.895	0.672	0.000	0.249
SE_BP	0.834	1.050	0.202	0.038	0.000	3.950	0.300	0.033	0.164	47.514	0.751	0.415	0.005	0.176
SE_BS	1.399	3.348	0.149	0.047	0.000	5.472	0.498	0.042	0.135	55.669	0.864	0.548	0.000	0.210
SE_DS	0.680	0.442	0.229	0.036	0.000	3.509	0.257	0.032	0.171	41.893	0.706	0.391	0.005	0.170
SE_KT	0.922	1.249	0.210	0.042	0.000	3.951	0.337	0.035	0.165	51.804	0.833	0.478	0.006	0.192

Table 6 Leaching function K parameters

Leaching function N parameters

	BARL	FALL	GRAE	GRAI	MAIF	OATS	OFAO	OFAR	POTA	PULS	RAPE	RYEM	SUGB	SWHE
DE_BP	15.796	13.812	14.499	14.498	15.825	15.825	15.841	43.025	15.822	152.756	15.782	15.857	15.770	15.787
DE_DS	18.425	16.427	17.779	17.568	18.638	18.344	18.323	45.955	18.349	155.200	18.440	18.302	18.403	18.487
DK_BP	12.009	9.978	10.555	10.680	11.962	11.905	11.914	39.079	12.331	148.977	11.908	11.997	13.303	11.965
DK_DS	15.209	13.193	13.751	14.073	15.910	15.570	16.104	43.257	15.801	152.426	15.319	15.605	14.338	15.131
DK_KT	15.330	13.299	14.026	14.240	15.364	15.273	15.374	42.550	15.332	152.334	15.282	15.303	14.269	15.287
EE_BP	9.924	0.000	0.000	7.583	0.000	9.924	0.000	7.924	9.917	77.053	9.922	9.930	0.000	9.920
EE_GF	9.748	0.000	0.000	7.287	0.000	9.748	0.000	7.748	9.743	76.859	9.763	9.751	0.000	9.750
EE_GR	10.437	0.000	0.000	7.803	9.712	10.437	0.000	8.437	10.438	77.530	10.439	10.431	9.479	10.433
FI_BB	8.094	6.201	4.713	4.556	0.000	8.275	7.629	5.722	8.222	86.876	8.437	8.203	8.527	8.518
FI_BS	9.712	7.735	6.550	7.027	9.950	9.641	9.690	7.547	9.401	88.345	9.724	9.839	9.862	9.948
FI_GF	9.638	7.636	6.909	6.773	10.162	9.440	9.017	7.060	9.467	88.543	9.827	9.837	10.059	10.099
LT_BP	12.485	0.000	0.000	10.096	12.330	12.745	0.000	28.319	12.678	69.896	12.410	12.648	12.595	12.426
LV_BP	12.473	0.000	0.000	9.624	12.643	12.301	0.000	17.973	12.418	72.917	12.760	12.457	12.420	12.478
LV_GR	11.030	0.000	0.000	8.391	11.156	10.983	0.000	19.316	11.014	67.603	11.141	11.021	11.018	11.043
PL_BP	15.440	14.898	14.169	13.187	15.935	15.366	17.068	28.523	15.109	91.207	15.776	15.554	15.637	15.394
RU_BP	12.411	0.000	0.000	9.653	13.717	12.762	0.000	23.991	12.221	67.214	13.042	12.528	12.292	13.051
RU_GF	9.236	6.655	5.840	7.136	9.882	8.791	8.017	10.101	9.384	63.828	9.723	9.320	9.368	9.573
SE_BB	6.628	4.574	3.752	3.763	0.000	6.572	6.585	4.562	6.501	85.063	6.391	6.506	0.000	6.645
SE_BP	10.537	8.265	8.764	8.765	0.000	10.244	11.235	8.960	11.803	100.997	10.412	11.179	12.494	10.792
SE_BS	8.071	5.962	5.058	5.061	0.000	8.338	6.978	5.395	7.721	80.226	8.779	8.708	0.000	8.253
SE_DS	13.677	11.682	11.327	11.300	0.000	13.679	13.727	11.672	13.690	124.211	13.679	13.691	13.674	13.674
SE_KT	13.323	10.702	11.059	11.045	0.000	12.777	13.380	10.994	13.832	101.279	13.322	13.410	14.873	13.438

Table 7 Leaching function N parameters

Leaching functions B parameters

	BARL	FALL	GRAE	GRAI	MAIF	OATS	OFAO	OFAR	POTA	PULS	RAPE	RYEM	SUGB	SWHE
DE_BP	0.803	0.768	1.255	1.307	1.153	0.512	1.014	1.364	1.200	-0.120	0.807	0.979	1.702	1.074
DE_DS	0.797	0.762	1.248	1.301	1.144	0.507	1.009	1.353	1.195	-0.121	0.801	0.976	1.696	1.067
DK_BP	0.813	0.778	1.264	1.316	1.163	0.522	1.025	1.375	1.209	-0.110	0.817	0.989	1.712	1.084
DK_DS	0.800	0.765	1.250	1.303	1.148	0.508	1.010	1.360	1.195	-0.123	0.804	0.975	1.701	1.071
DK_KT	0.795	0.760	1.246	1.298	1.145	0.504	1.006	1.356	1.191	-0.128	0.799	0.971	1.702	1.066
EE_BP	0.795	0.000	0.000	1.298	0.000	0.504	0.000	1.357	1.192	-0.127	0.799	0.972	0.000	1.066
EE_GF	0.797	0.000	0.000	1.299	0.000	0.506	0.000	1.359	1.194	-0.125	0.801	0.973	0.000	1.068
EE_GR	0.798	0.000	0.000	1.301	1.138	0.507	0.000	1.359	1.194	-0.125	0.802	0.974	1.684	1.069
FI_BB	0.791	0.758	1.235	1.290	0.000	0.502	1.000	1.351	1.189	-0.132	0.798	0.969	1.689	1.063
FI_BS	0.802	0.767	1.248	1.304	1.155	0.510	1.013	1.362	1.196	-0.121	0.806	0.978	1.701	1.074
FI_GF	0.802	0.767	1.251	1.304	1.156	0.510	1.008	1.359	1.197	-0.119	0.807	0.979	1.703	1.075
LT_BP	0.791	0.000	0.000	1.296	1.134	0.505	0.000	1.356	1.192	-0.128	0.792	0.970	1.691	1.059
LV_BP	0.786	0.000	0.000	1.292	1.135	0.496	0.000	1.348	1.183	-0.138	0.789	0.962	1.685	1.057
LV_GR	0.791	0.000	0.000	1.294	1.137	0.503	0.000	1.354	1.189	-0.129	0.793	0.969	1.686	1.060
PL_BP	0.789	0.768	1.248	1.291	1.140	0.497	1.014	1.356	1.182	-0.133	0.798	0.962	1.687	1.058
RU_BP	0.794	0.000	0.000	1.297	1.140	0.502	0.000	1.357	1.191	-0.129	0.796	0.970	1.693	1.063
RU_GF	0.795	0.758	1.240	1.299	1.137	0.502	0.997	1.354	1.195	-0.123	0.801	0.975	1.695	1.068
SE_BB	0.792	0.757	1.241	1.293	0.000	0.501	1.003	1.353	1.188	-0.132	0.796	0.951	0.000	1.063
SE_BP	0.798	0.764	1.246	1.298	0.000	0.508	1.007	1.357	1.193	-0.124	0.803	0.972	1.692	1.068
SE_BS	0.795	0.760	1.246	1.298	0.000	0.505	1.004	1.355	1.191	-0.128	0.800	0.973	0.000	1.066
SE_DS	0.799	0.764	1.251	1.303	0.000	0.507	1.010	1.360	1.195	-0.124	0.803	0.974	1.697	1.070
SE_KT	0.795	0.760	1.246	1.298	0.000	0.503	1.007	1.356	1.192	-0.128	0.799	0.971	1.696	1.066

Table 8 Leaching function B parameters

From this leaching function the reduction in leached nitrogen is calculated as:

$$\Delta L_{c,I}(N_{c,I}) = A_{c,I}(L_{c,I}(N^{*}_{c,I}) - L_{c,I}(N_{c,I}))$$

This equation calculates the reduction in nitrogen leaching as the difference between the leached amount initially and at the reduced nitrogen application $N_{c,I}$ on the crop areas $A_{c,I}$.

Before the leached nitrogen from fertilisation ends up in the Baltic Sea some of the nitrogen is further retained in the groundwater and surface water on its way towards the sea. Estimates of both groundwater and surface water retentions are provided by MESAW (Stålnacke et al 2011) and are afterwards aggregated to drainage basin level by an area based weighting procedure. This produces a crop and drainage specific retention of both groundwater and surface water. The spatial aggregation and area weighting are described in chapter 5 in this report. Retentions are reported as the percentage of nitrogen that is retained in groundwater and surface water respectively. Including the retentions the effective reduction in the Baltic Sea can be calculated as:

$$\Delta N_{c,I}^{EFF}(N_{c,I}) = (1 - \frac{R_{c,I}^{SURF}}{100})(1 - \frac{R_{c,I}^{GRW}}{100})\Delta L_{c,I}(N_{c,I})$$

This equation describes the effective reduction of nitrogen load to the sea by putting the reduction in leached nitrogen through the retention chain of groundwater and surface water. The parameters R^{SURF} and R^{GRW} are the percentages of nitrogen retained in surface water and groundwater which makes (1- R^{SURF}/100) and (1- R^{GRW}/100) the percentages of nitrogen that is not retained and thus end up in the sea. The effective reduction is thus defined as the reduction in leaching times the percentages if nitrogen that is not retained in groundwater or surface water. The crop and drainage basin specific retentions are reported in table 9 and 10.

	Groundwater retentions (percent of N retained)													
	BARL	FALL	GRAE	GRAI	MAIF	OATS	OFAO	OFAR	POTA	PULS	RAPE	RYEM	SUGB	SWHE
DE_BP	60.89	60.43	60.43	60.62	60.29	60.13	60.08	60.12	60.60	60.40	60.91	59.85	60.97	60.96
DE_DS	76.07	76.07	76.10	76.12	76.04	76.08	76.08	76.03	76.08	76.08	76.06	76.08	76.07	76.06
DK_BP	8.34	6.42	1.37	6.66	4.40	1.03	2.14	1.80	23.26	5.17	3.24	6.70	77.00	5.89
DK_DS	68.99	68.32	71.21	67.86	73.78	65.81	72.62	71.50	70.63	70.23	68.52	68.38	66.53	68.35
DK_KT	56.51	57.20	61.42	55.06	54.45	58.49	52.97	53.85	54.30	53.83	59.35	57.25	88.69	59.13
EE_BP	0.00	100.00	100.00	0.00	100.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
EE_GF	0.62	100.00	100.00	0.26	100.00	0.62	100.00	0.62	0.63	0.34	0.64	0.55	100.00	0.65
EE_GR	16.53	100.00	100.00	15.66	11.04	16.53	100.00	16.53	16.62	16.35	16.66	16.52	7.16	16.50
FI_BB	42.36	42.10	45.43	38.34	100.00	43.25	37.08	37.17	44.07	47.85	46.11	42.03	52.08	50.21
FI_BS	19.17	18.91	10.74	15.11	18.24	17.66	16.99	17.38	17.07	20.06	19.27	19.65	19.22	22.77
FI_GF	34.02	35.25	33.96	27.29	42.86	29.61	22.18	24.41	29.74	43.75	38.97	39.36	42.29	49.04
LT_BP	56.17	100.00	100.00	56.50	55.62	56.67	100.00	56.38	56.55	56.51	56.05	56.50	56.32	55.99
LV_BP	19.42	100.00	100.00	17.30	20.54	18.07	100.00	18.66	19.09	22.05	21.50	19.34	19.11	19.55
LV_GR	4.26	100.00	100.00	2.76	6.62	2.42	100.00	3.07	3.26	2.69	5.50	3.02	5.49	4.89
PL_BP	70.41	75.97	73.89	69.93	72.76	69.91	76.00	68.92	69.44	68.43	71.62	69.96	70.93	69.92
RU_BP	77.25	100.00	100.00	75.53	96.78	82.46	100.00	71.20	74.47	76.79	86.59	79.02	75.43	86.86
RU_GF	37.04	17.90	9.88	50.82	59.00	24.59	4.48	28.51	44.65	41.50	49.99	42.71	31.90	46.39
SE_BB	13.17	12.85	12.08	11.66	100.00	12.98	12.79	13.53	13.18	19.00	19.00	19.00	100.00	12.79
SE_BP	46.78	46.41	34.15	34.11	100.00	50.52	38.44	38.50	36.73	45.75	44.44	37.00	38.45	40.52
SE_BS	43.99	46.43	37.14	37.31	100.00	48.67	28.95	34.87	33.29	64.79	66.42	56.48	100.00	55.94
SE_DS	33.00	33.00	33.01	33.01	100.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00
SE_KT	10.05	4.87	7.03	6.97	100.00	3.68	10.32	6.62	13.88	8.83	10.27	10.79	31.00	10.34

Table 9 Area weighted groundwater retentions

	Surface water retentions (percent of N retained)													
	BARL	FALL	GRAE	GRAI	MAIF	OATS	OFAO	OFAR	POTA	PULS	RAPE	RYEM	SUGB	SWHE
DE_BP	20.21	20.47	20.47	20.36	20.55	20.64	20.67	20.64	20.37	20.48	20.19	20.80	20.16	20.17
DE_DS	28.82	28.82	28.73	28.68	28.89	28.77	28.79	28.93	28.79	28.78	28.82	28.79	28.80	28.84
DK_BP	2.54	2.42	2.09	2.43	2.29	2.07	2.14	2.12	3.51	2.34	2.21	2.43	7.00	2.38
DK_DS	10.10	10.13	9.80	11.35	12.30	11.66	13.10	13.09	11.96	10.53	10.27	11.07	8.54	9.88
DK_KT	12.75	12.68	11.46	13.01	13.33	12.55	13.69	13.49	13.49	13.58	12.05	12.76	4.98	12.12
EE_BP	8.54	100.00	100.00	9.06	100.00	8.54	100.00	8.54	8.62	8.55	8.47	8.55	100.00	8.57
EE_GF	8.52	100.00	100.00	8.21	100.00	8.52	100.00	8.52	8.52	8.28	8.53	8.46	100.00	8.54
EE_GR	6.71	100.00	100.00	7.35	9.03	6.71	100.00	6.71	6.73	6.78	6.74	6.74	9.72	6.72
FI_BB	23.83	23.95	27.47	30.24	100.00	22.96	26.98	26.91	22.61	21.46	21.60	23.51	19.28	20.53
FI_BS	36.33	37.69	30.46	41.34	24.76	41.34	44.12	41.11	36.01	33.09	36.82	36.50	34.99	25.78
FI_GF	37.17	36.92	41.51	45.97	21.91	42.39	51.99	50.61	42.48	28.77	32.08	31.74	27.37	23.72
LT_BP	29.67	100.00	100.00	29.80	29.44	29.87	100.00	29.75	29.82	29.80	29.62	29.80	29.73	29.59
LV_BP	16.00	100.00	100.00	16.00	16.00	16.00	100.00	16.00	16.00	16.00	16.00	16.00	16.00	16.00
LV_GR	17.45	100.00	100.00	18.81	15.90	19.11	100.00	18.37	18.42	19.78	17.06	18.75	15.71	16.83
PL_BP	29.90	30.00	30.51	30.26	30.32	30.20	30.00	31.27	31.01	30.20	28.49	30.33	30.30	30.15
RU_BP	46.00	100.00	100.00	45.92	46.86	46.23	100.00	45.73	45.87	45.98	46.41	46.07	45.92	46.42
RU_GF	44.14	31.77	32.83	52.85	56.00	38.32	33.24	42.94	50.17	48.30	50.30	48.72	33.53	48.10
SE_BB	39.56	38.98	36.29	36.46	100.00	38.92	39.01	38.73	37.79	37.00	37.00	37.00	100.00	39.57
SE_BP	47.54	51.16	48.24	48.24	100.00	54.15	44.89	47.31	41.32	50.11	48.88	40.73	27.25	46.01
SE_BS	38.84	38.52	39.62	39.55	100.00	38.83	38.43	38.74	39.12	37.51	37.46	38.20	100.00	37.85
SE_DS	9.00	9.00	9.00	9.00	100.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
SE_KT	46.38	52.15	47.97	48.06	100.00	53.24	46.17	50.72	41.55	47.62	47.02	46.40	27.65	46.75

Table 10 Area weighted surface water retentions

2.1.7. Combining costs and effects

From the cost calculations and the constructed profit function we can establish the cost in terms of lost profit from fertiliser reductions at the source. The reduction at source can subsequently be recalculated to the effective reduction in the Baltic Sea through the leaching function and the retention chain. Thus we can establish the cost of the effective reduction through this relationship. For a marginal reduction this can be illustrated as follows:

$$\text{Cost} = \frac{\partial \pi_{c,I}(N_{c,I})}{\partial N_{c,I}}$$

$$\text{Effect} = (1 - \frac{R^{SURF}_{c,I}}{100})(1 - \frac{R^{GRW}_{c,I}}{100})\frac{\partial L_{c,I}(N_{c,I})}{\partial N_{c,I}}$$

This relationship between costs and effective reductions in the Baltic Sea is illustrated in figure 4 exemplified by wheat in the drainage basin Denmark into Baltic Proper. For simplicity the figure illustrates the cost function of reduction on 1 hectare for one crop in one drainage basin.

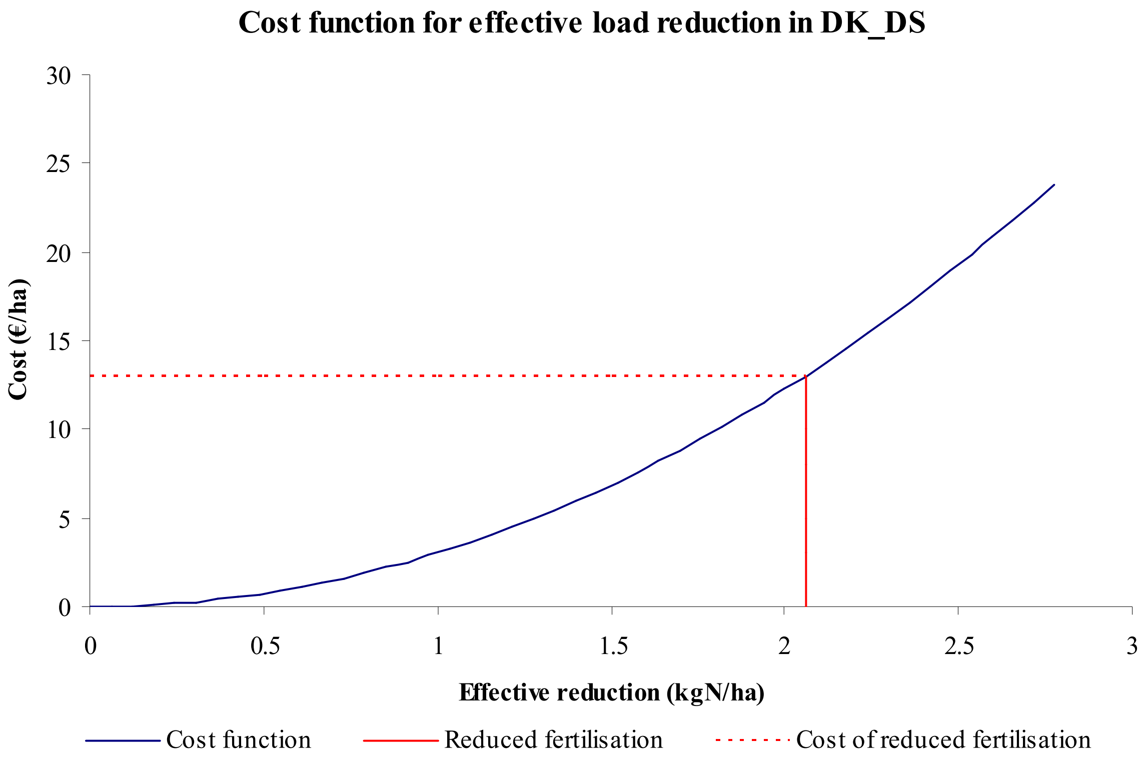

Figure 4 Cost function for effective reductions to the sea. The red line illustrates the same reduction as figures 2 and 3.

The cost function for effective reductions essentially has the same shape as the cost function for reductions at source. However, the slope is much steeper for the effective reductions because of the leaching function and retentions which decrease the effect of a reduction at source. This is apparent from the scale of the x-axis where it can be seen that the reduction at source in figure 3 corresponds to a much smaller effective reduction in the sea. Since the reduction is the same the cost is unchanged, but the load reduction is much smaller after calculations of leaching and retentions.

2.1.7. The capacity for fertiliser reductions

The potential for fertiliser reduction is set to 20% of the initial fertiliser application. The reason for choosing this limitation is that reduction outside this range is likely to influence the parameters of the yield functions. Increasing this limitation can thus lead to faulty results as the shape of the yield functions will change due to depletion of the nitrogen stock in the soil.

Since the modelled yield functions are not dependant on long term effects but only describe the short term dose-response relationship between nitrogen and crop yield, we therefore limit the potential to the interval where we feel confident that the functions are suitable for describing this relationship. A shift in the yield function would translate directly to a shift in the profit function as described earlier. Larger reductions would therefore be likely to be associated with much larger costs as the profit function would shift downwards. The capacity limit at 20% is somewhat arbitrary however, as the realistic capacity limit, following the described logic, will be different between both crops and locations. We don’t have the information available to estimate differentiated capacity constraints however.

2.1.8. Discussion of assumptions

Missing data on fertiliser application, yield and prices necessitates some substitution of prices, yields or even entire functions between countries. This has been discussed in the data section, but we would point out here that some of the substitution assumptions have been somewhat arbitrary, but necessary.

We have also experienced that the calibration procedure resulted in functions that are not reasonable for the crops in question. In the case of sugar beets all the calibrated functions had very high base yields (constant terms in the yield functions). Some countries had constants of over thrice the size of the Danish experimental functions. For this reason the experimental function for sugar beets are used for all countries as it is deemed more reasonable than the calibrated functions. As the tendency of enormous base yields for this crop was persistent over all other countries we have judged it to be an artefact of the calibration procedure and the fact that sugar beets have very high yields per hectare (on account of the heaviness of the crop) and relatively low prices per hkg. Putting the increased yield by increasing fertilisation by one unit equal to the relative prices in equation (4) thus results in a very high value of the productivity scaling parameter θ_j which is unlikely considering the relative productivity on other crops.

For fodder crops the calibration procedure did not work as intended. This is the case for the fodder crop functions of grass and green maize. .For this reason we do not have good prices for performing the calibration procedure. This results in implausible functions with a very large constant term (base yield at no fertilisation) and very little curvature. The procedure also fails for potatoes and sugar beets. These functions are special as they are quite steep and have much curvature because of the heaviness of the output (tubers) but the calibration procedure does not produce functions that are plausible when compared to real observed yields. For this reason we choose to rescale the experimental Danish functions rather than calibrate new functions. This rescaling is made by calculating the ratio between observed yields in Denmark and the country ion question from Eurostat and applying this ratio as a weighting of the constant term of the functions. This is a level shift of the function depending on observed yields that does not influence the slope and curvature of the functions. In practical terms this is a scaling of the function with respect to general agricultural productivity but with no scaling with respect to the productivity of nitrogen input. This scaling is accomplished by calculating the adjustment weight CW as:

$$CW_{c,I1} = \frac{y_{c,I1}^{AVG}}{y_{c,DK}^{AVG}}$$

where y^{AVG} are the average observed yields for crop c in the countries $I1$ and DK respectively. This weighting is then applied to the Danish experimental by:

$$y_{c,I1} = CW_{c,I1} * \alpha_{c,DK} + \beta_{c,DK} N + \gamma_{c,DK} N^2$$

This function shifts the experimental function up or down depending on the ratio of the observed yields.

Another point to notice is the substitutions of different prices and yields between countries. Particularly for Russia and Belarus where prices have been taken from Russia and yields from Belarus the substitution has an undesirable effect on the calibration. Since the functions of the two countries are effectively "borrowing" the missing data from each other the functions become the same for both. Therefore there is no difference between the functions for Russia and Belarus

Some of the crops included are not usually traded at market prices. For some fodder crops this makes pricing difficult because fodder crops are intermediate factors of production rather than marketable output. This lack of observable value makes cost calculations questionable. An effort was made to valuing these crops by their standard output (SO), but this approach gives a downward sloping profit function which results in profitable reductions. The problem is present for green maize (MAIF) and other fodder crops (OFAO). For this reason these crops are omitted from the reduction potential as it is not possible to make reliable calculations. For the case of other fodder crop the heterogeneity of the 'crop' further makes difficulties in determining the relevant yield function which might even differ among countries as what constitutes other fodder will vary between soil and climate conditions. A downward sloping profit function results in an optimal fertiliser application of 0 and so any reduction will cause a net benefit. Since the optimisation model is calculating costs for reductions omitting these crops from the reduction potential can be accomplished by setting the initial fertiliser application to 0 which prevents any possible reduction.

As mentioned above the optimisation model only considers reductions and costs and not absolute amounts. Therefore the parameters of interest are changes in fertilisation rather then absolute level of fertilisation. Hans Estrup Andersen (Andersen et al 2011) have supplied data of the modelled current fertilisation rates. Since this data is not related to the yield functions there is a potential for profitable reductions in some drainage basins where the modelled fertilisation exceeds the economic optimum. For this reason we have chosen to use the economic optimum as the initial fertilisation rate. Since the model calculates changes in the fertilisation rate rather than the absolute level this does not fundamentally impair the results of the model. However, it does affect the assumed initial fertilisation. Table 11 reports the percentage differences between the modelled initial fertilisation rates and the calculated economic optimums based on the profit functions defined as the modelled fertiliser use in percent of the economic optimum. Values over 100% thus signifies a modelled fertiliser use over the economic optimum and vice versa. For MAIF and OFAO the reduction potential is set to 0 as described above and for pulses (PULS) there is some fertilisation in the modelled data in Germany, Poland and Denmark but no fertilisation in the economic maximum as pulses fixate nitrogen from the air and thus have no observable yield function in Pedersen (2009). The percentage changes can therefore not be calculated and is set to 0 for these crops. Fertiliser use on fallow land is zero in both cases and is therefore considered equal.

Initial N application from modelled data in percent of the economic optimum

	BARL	FALL	GRAE	GRAI	MAIF	OATS	OFAO	OFAR	POTA	PULS	RAPE	RYEM	SUGB	SWHE
DE_BP	156	100	26	33	0	132	0	113	71	0	104	120	168	102
DE_DS	168	100	47	46	0	146	0	122	70	0	108	130	203	103
DK_BP	122	100	21	28	0	110	0	104	70	0	111	89	222	107
DK_DS	130	100	37	44	0	137	0	117	69	0	115	105	208	108
DK_KT	134	100	42	47	0	145	0	123	72	0	115	108	188	109
EE_BP	115	100	0	6	0	123	0	33	29	0	64	134	0	131
EE_GF	107	100	0	6	0	115	0	30	26	0	55	131	0	127
EE_GR	112	100	0	6	0	121	0	31	28	0	58	136	99	131
FI_BB	93	100	35	24	0	93	0	55	32	0	108	111	134	126
FI_BS	91	100	36	15	0	91	0	54	31	0	106	107	128	124
FI_GF	89	100	34	14	0	89	0	54	31	0	104	106	125	123
LT_BP	108	100	0	21	0	111	0	65	86	0	95	100	204	100
LV_BP	117	100	0	8	0	113	0	34	35	0	103	102	74	94
LV_GR	112	100	0	8	0	112	0	33	65	0	86	103	78	94
PL_BP	184	100	35	25	0	127	0	42	57	0	97	185	174	143
RU_BP	182	100	0	57	0	149	0	148	56	0	177	133	118	170
RU_GF	145	100	110	38	0	159	0	146	43	0	100	111	152	122
SE_BB	83	100	31	28	0	87	0	10	4	0	75	79	0	4
SE_BP	26	100	8	7	0	13	0	9	20	0	20	33	149	25
SE_BS	111	100	37	30	0	122	0	27	5	0	88	0	0	56
SE_DS	145	100	58	61	0	152	0	61	51	0	108	108	222	105
SE_KT	132	100	48	42	0	136	0	50	48	0	105	24	166	94

Table 11.

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Annex 2.2. Catch crops under spring-sown cereals (N abatement)

Authors: Hasler B., Fonnesbech-Wulff A., Mathiesen G.B. Smart J.C.R., Andersen H.E.

This annex describes how the costs of growing catch crops as a measure to reduce nitrogen loads are portrayed in the BALTCOST model for identifying the lowest cost combination of abatement measures for delivering specified reduction targets for nitrogen (N) and phosphorus (P) loads into 7 sea regions of the Baltic Sea. Catch crops is one of 5 abatement measures considered by the current version of BALTCOST.

The description of the catch crop measure in BALTCOST proceeds in the following sequence:

- the catch crop measure
- assumptions and methodology for estimating the catch crop costs
- data sources used in estimating the costs
- effects of catch crops on N and P loads into the river systems and thence into the receiving sea regions in the Baltic
- capacity for implementing catch crops

2.2.1. Catch crops as a measure to reduce nutrient loads

Catch crops are grown to catch nutrients in the period in between two main crops, and the catch crops are either undersown in the main crop, or sown after the main crop. Ray grass is often used as a catch crop, and it is most often undersown in spring barley (Hasler et al 2009) For the modelling of catch crops we have assumed that the catch crops are undersown in spring crops, and that the catch crops is ray grass.

2.2.2. Methodology and data for the cost estimation

Catch crops undersown as ray grass in spring cereals (spring barley) is not assumed to cause yield effects in the main crop (Hasler et al 2009). The costs are estimated in Danish prices, and comprise the costs of sowing and the costs of seeds. As mentioned the catch crop will often be sown together with the main crop and this is assumed for these cost-estimations. Additional costs that will be realistic if the catch crop is sown after the harvest of the main crop are not included.

The average cost of sowing catch crops is estimated to EUR 60 in 2007 prices. Deflated to 2005 prices the costs of catch crops in DK are EUR 58 per hectare (Hasler et al 2009).

The costs for the other countries are estimated adjusting the prices with the standard output (SO) (the standard output has as an economic measure replaced the former Standard Gross Margin) for temporary grass, which reflects the differences in outputs from the catch crop in the different countries. Since we do not assume any yield effects the SO for temporary grass is used instead of the SO for spring crops, e.g. spring barley...

The standard outputs for temporary grass in the 9 countries are presented in table 2.2.1. The standard outputs are retrieved from Eurostat (2004), and are estimated in 2005 prices. A ratio of the standard output in each of the countries and the Danish SO is estimated, and used for the estimation of the adjusted costs of growing catch crops in each country. The final costs of catch crops can be seen from the right column in table 2.2.1.

Table 2.2.1. The estimated costs of catch crops

Country	Avg. SO for temporary grass	Ratio Countr/DK	Cost of catchcrop (2005 EUR/ha)
SE	539	0,61	35
RU	77	0,09	5
PL	301	0,34	20
LV	30	0,03	2
LT	77	0,09	5
FI	629	0,71	41
EE	236	0,27	15
DK	889	1,00	58
DE	538	0,60	35
BY	77	0,09	5

Source: FADN, Eurostat, and own calculations

The data for the costs are retrieved from the Danish assessment of costs of measures to implement the Water Framework Directive (Hasler et al 2009) and the standard outputs used for the calibration of the costs between the countries are from Eurostat:"Standard Output 2004 - Value of production EURO/t". The source is FADN, the downloaded data from Eurostat are "Standard output (SO) coefficients used for typology [ef_tso]" .

The calculated per hectare cost of catch crops lead to the linear cost function:

$$Cost_I = C_I^{CC} * CC_I$$

where C^{CC} is the cost per hectare reported in table 2.2.1. and *CC* are the hectares undersown with catch crops in country *I*.

2.2.3.The effects of catch crops on nitrogen leaching

It is well known that catch crops growing after a traditional crop can take up a significant amount of nitrate during autumn and early winter and thereby reduce the nitrate leaching during the period with percolation (Martinez & Guiraud, 1990; Thomsen et al., 1993). But the reducing effect of the catch crops on N leaching shows large variation between years, sites, input of fertiliser and manure, soil and climatic drivers as precipitation and temperature (Lewan, 1994; Thomsen, 1995; Stenberg at al., 1999). From several studies mainly in Denmark and Sweden catch crops are able to reduce nitrogen leaching by 50 pct. or more (Torstensson & Aronsson, 2000; Thomsen, 2005; Hansen & Djurhuus, 1997; Thomsen & Christensen, 1999). A study in south-western Finland found a reduction in N leaching with undersown ryegrass of 52, 31, 68 and 27 pct. in clay, silt, sand and peat soil, respectively (Lemola et al., 2000).

Catch crop can have opposite effects, however. Apart from their ability to reduce leaching they also have an effect as input of organic matter into the soil and will increase the mineralization and hence increase the nitrate leaching. A 24 year old Danish field trial of spring-sown crops with and without catch crops found that an average N leaching for 4 yr was 14 kg N/ha/year or 29 pct. higher in plots with long term incorporation of the catch crops than in plots without (Hansen et al., 2000).

In Thomsen & Christensen (1999) catch crops halved the total N leaching, but lysimeters previously undersown with ryegrass lost more nitrate than lysimeters with no history of ryegrass. The extra loss of nitrate accounted for 30 pct of the N retained by the ryegrass catch crop.

A net reducing effect on N leaching by introducing catch crops in spring sown crops can then be estimated to 35 pct. of the initial leaching when the effect of catch crops on 50 pct is corrected for the extra N-leaching of the incorporated catch crop biomass on 30 pct of the of the N retained by the catch crop. Further adjustment of crop cover during period with perkolation may be able minimize the extra N leaching effect of incorporated catch crop biomass. The effectiveness calculations for the catch crops thus go through the leaching function for arable land estimated by Hans Estrup Andersen (Andersen et al 2011) which is more closely described in the section about fertiliser reductions. The effect is determined as 35 pct. of the initial leaching which can be formalised as:

$$\Delta N_I^{CC} = 0.35 * L_{c,I}(N_{c,I}^*) = 0.35 * K_{c,I}(N_{c,I}^* + N_{c,I}^S)^{B_{c,I}}$$

where ΔN^{CC} is reduction in N leaching per hectare by sowing catch crops and N^* is the N application. The parameters of the leaching function are described in section

The yield of the crop after a catch crop increases when the catch crop's biomass is incorporated into the soil compared with no catch crops incorporation. With long term use of catch crop Hansen et al., (2000) estimated that N fertilization to the following crops can be reduced with about 25 pct.. To prevent extra leaching from incorporated catch crops fertiliser input for the following crop is recommended to be reduced by 25 pct.

In the cost-estimations we have assumed a small yield loss effects, similar to the assumed yield loss at Danish clay soils (Hasler et al 2009).

2.1.3. The capacity constraint

The capacity for growing catch crops are estimated as the area grown with spring cereals, i.e. spring barley and oats, i.e. the capacity/potential equals the current area cultivated with these spring cereals.

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Annex 2.3. Reductions in livestock numbers (N & P abatement)

Authors: Fonnesbech-Wulff A., Hasler B., Smart J.C.R, Smedberg E.

This annex describes how reductions in livestock numbers to reduce nitrogen and phosphorus loads are portrayed in the BALTCOST model for identifying the lowest cost combination of abatement measures for delivering specified reduction targets for nitrogen (N) and phosphorus (P) loads into 7 sea regions of the Baltic Sea.The measure is one of 5 abatement measures considered by the current version of BALTCOST.

The description of the reduced livestock measure in BALTCOST proceeds in the following sequence:

- the livestock reduction measure
- methodology for estimating the cost function
- data sources used in estimating the cost function
- effects of reduced livestock production on N and P loads into the river systems and thence into the receiving sea regions in the Baltic
- capacity for implementing livestock reductions

2.3.1. Reduction in livestock production as a measure to reduce nitrogen and phosphorus loads

In the model there are two types of livestock in which reductions can take place. These two general types are cattle and pigs, respectively. However, one unit of livestock from one of these groups is a heterogeneous unit.

In the dataset provided by Andersen (Andersen et al 2011) there are five categories of cattle and five categories of pigs based on the livestock classes defined by EuroStat. For cattle these classes are: Bovine young which are up to two years old (PC1_PC2), bovine male which are male animals over 2 years of age (PC3100), heifers (PC3210), dairy cows (PC3221) and other cows (PC3222). For pigs the classes are: Piglets weighing less than 20 kg (PP1000), pigs weighing between 20 and 50 kg (PP2000), fattening pigs weighing more than 50 kg (PP3000), boars (PP4100) and sows (PP4200). To make reductions in just one of these classes has the potential to produce infeasible results because of the inherent interconnectedness of the livestock classes (e.g. reducing the number of sows without reducing the number of piglets or reducing the number of young bovine while maintaining the number of dairy cows). To avoid these restrictions and the micromanagement rules that would have to be formulated in the model we make a weighted aggregation of the livestock into the two general types of cattle and pigs. The following section describes this aggregation and the data material applied in the process.

2.3.2. Methodology to estimate the costs of livestock reductions

To be able to quantify the cost and effect of a reduction in the number of units of either cattle or pigs we aggregate livestock classes from EuroStat into the two main groups of cattle and pigs. This aggregation calculates a representative average animal for each drainage basin and livestock type that is used as the unit of reduction, cost calculation and efficiency. The point of departure is a weighted average of the livestock classes that make up the collective herd in each drainage basin. The weighting scheme for these calculations uses the data supplied from Hans Estrup Andersen [Andersen et al 2011] to calculate the share of each livestock class in each drainage basin by the formula

$$W_{L,D}^{Cattle} = \frac{LC_{L,D}^{Cattle}}{\sum_{L} LC_{L,D}^{Cattle}}$$

$$W_{L,D}^{Pigs} = \frac{LC_{L,D}^{Pigs}}{\sum_{L} LC_{L,D}^{Pigs}}$$

where $W_{L,D}$ is the weight assigned to each livestock class, L, in each drainage basin, D, for cattle and pigs respectively. $LC_{L,D}$ is the number of livestock of class L in drainage basin D and the sum of these is the total number of livestock in the drainage basin. Thus we have a weighting that constitutes the share of each livestock class of the total number of each livestock type in each drainage basin. The numbers and calculated shares are reported in table 1 and 2.

	Number of livestock in each livestock class (cattle)					Number of livestock in each livestock class (pigs)				
	PC1_PC2	PC3100	PC3210	PC_3221	PC_3222	PP1000	PP2000	PP3000	PP4100	PP4200
DE_BP	95385	2779	15252	105811	43082	93389	105603	136676	525	44697
DE_DS	243859	7346	52588	219172	50886	227149	210428	339733	1985	79270
DK_BP	4072	14	510	2339	1093	22848	21349	24601	14	6798
DK_DS	253081	3979	21140	172270	32592	1299770	1109771	1041366	3012	405743
DK_KT	372228	3905	32141	240395	50714	1971944	1702603	1556196	4468	612049
EE_BP	8258	142	1713	13798	189	12298	9912	12593	177	4454
EE_GF	9659	166	2004	16140	221	14385	11594	14730	207	5209
EE_GR	24887	426	5134	41616	572	36866	29779	38010	533	13390
FI_BB	106640	2145	9015	103642	6920	68092	51041	87780	985	32729
FI_BS	72449	2113	7064	69771	9243	146595	115260	197669	1953	70738
FI_GF	67435	1943	6467	66588	7723	132884	104464	181839	1712	62893
LT_BP	140705	7251	739670	720407	3518	167041	211674	1469248	2713	79263
LV_BP	34654	1087	5762	74860	950	33787	41061	77687	663	17124
LV_GR	115652	2680	363750	444410	3264	108623	122730	714004	2186	54237
PL_BP	1257855	69045	345208	2906709	71860	5753310	4433426	6114505	43517	1692550
RU_BP	28497	1030	28192	76937	1768	75930	65826	122103	874	23623
RU_GF	96173	1947	385187	390428	4766	82362	63742	613647	1279	34443
SE_BB	33474	846	3193	23199	2080	7081	6931	10247	96	2582
SE_BP	416967	13896	45324	169663	91245	229501	174622	209472	1185	51779
SE_BS	109778	4407	12195	46635	24495	27122	22624	27986	123	6433
SE_DS	25079	776	2670	8552	7506	26469	21904	24881	217	6351
SE_KT	282573	9365	30163	120665	56964	177593	139149	167158	846	41978

Table 11 Numbers of livestock by class and type

	Weights for livestock classes (cattle)					Weights for livestock classes (pigs)				
	PC1_PC2	PC3100	PC3210	PC_3221	PC_3222	PP1000	PP2000	PP3000	PP4100	PP4200
DE_BP	0.364	0.011	0.058	0.403	0.164	0.245	0.277	0.359	0.001	0.117
DE_DS	0.425	0.013	0.092	0.382	0.089	0.265	0.245	0.396	0.002	0.092
DK_BP	0.507	0.002	0.064	0.291	0.136	0.302	0.282	0.325	0.000	0.090
DK_DS	0.524	0.008	0.044	0.357	0.067	0.337	0.288	0.270	0.001	0.105
DK_KT	0.532	0.006	0.046	0.344	0.073	0.337	0.291	0.266	0.001	0.105
EE_BP	0.343	0.006	0.071	0.573	0.008	0.312	0.251	0.319	0.004	0.113
EE_GF	0.343	0.006	0.071	0.573	0.008	0.312	0.251	0.319	0.004	0.113
EE_GR	0.343	0.006	0.071	0.573	0.008	0.311	0.251	0.321	0.004	0.113
FI_BB	0.467	0.009	0.039	0.454	0.030	0.283	0.212	0.365	0.004	0.136
FI_BS	0.451	0.013	0.044	0.434	0.058	0.275	0.217	0.371	0.004	0.133
FI_GF	0.449	0.013	0.043	0.443	0.051	0.275	0.216	0.376	0.004	0.130
LT_BP	0.087	0.004	0.459	0.447	0.002	0.087	0.110	0.761	0.001	0.041
LV_BP	0.295	0.009	0.049	0.638	0.008	0.198	0.241	0.456	0.004	0.101
LV_GR	0.124	0.003	0.391	0.478	0.004	0.108	0.123	0.713	0.002	0.054
PL_BP	0.270	0.015	0.074	0.625	0.015	0.319	0.246	0.339	0.002	0.094
RU_BP	0.209	0.008	0.207	0.564	0.013	0.263	0.228	0.423	0.003	0.082
RU_GF	0.109	0.002	0.438	0.444	0.005	0.104	0.080	0.771	0.002	0.043
SE_BB	0.533	0.013	0.051	0.369	0.033	0.263	0.257	0.380	0.004	0.096
SE_BP	0.566	0.019	0.061	0.230	0.124	0.344	0.262	0.314	0.002	0.078
SE_BS	0.556	0.022	0.062	0.236	0.124	0.322	0.268	0.332	0.001	0.076
SE_DS	0.563	0.017	0.060	0.192	0.168	0.332	0.274	0.312	0.003	0.080
SE_KT	0.565	0.019	0.060	0.241	0.114	0.337	0.264	0.317	0.002	0.080

Table 12 Weights for livestock classes by type

The calculated weights are the basis for the calculations of costs and effects for reductions of livestock in the model.

2.3.3. Cost calculations

The cost calculations that determine the cost of livestock reduction are composed of two parts. Establishing the cost of a unit reduction of each livestock class and type and employing the weights from table 2 to aggregate these costs to a one unit reduction of a livestock type. For determining the costs of reduction of livestock we use the standard output (SO) of each livestock class which is obtained from EuroStat. The SOs of each livestock class are reported in table 3. For each drainage basin we have used the SO from the most fitting NUTS regions compared to the drainage basins for which the SO data is available (e.g. DE_BP is SO for Mecklenburg Vorpommern while DE_DS is an average of SOs from Mecklenburg Vorpommern and Schleswig-Holstein, see table in the wetland annex). For Russia where no SO data is available we have used Lithuanian values, solely based on geographical arguments.

	SO for livestock classes in € (cattle)					SO for livestock in € (pigs)				
	PC1_PC2	PC3100	PC3210	PC_3221	PC_3222	PP1000	PP2000	PP3000	PP4100	PP4200
DE_BP	478.22	569.55	186.85	2126.59	446.14	70.00	210.02	210.02	210.02	892.93
DE_DS	494.47	581.93	215.73	2009.69	446.14	70.00	211.90	211.90	211.90	900.80
DK_BP	295.54	283.01	314.32	2411.57	491.84	170.94	170.94	170.94	170.94	884.02
DK_DS	295.54	283.01	314.32	2411.57	491.84	170.94	170.94	170.94	170.94	884.02
DK_KT	295.54	283.01	314.32	2411.57	491.84	170.94	170.94	170.94	170.94	884.02
EE_BP	301.67	183.00	244.60	1341.00	384.00	72.00	182.00	182.00	182.00	442.00
EE_GF	301.67	183.00	244.60	1341.00	384.00	72.00	182.00	182.00	182.00	442.00
EE_GR	301.67	183.00	244.60	1341.00	384.00	72.00	182.00	182.00	182.00	442.00
FI_BB	407.56	334.22	2101.43	2476.28	359.83	130.89	130.89	130.89	130.89	130.89
FI_BS	407.56	334.22	2101.43	2476.28	359.83	130.89	130.89	130.89	130.89	130.89
FI_GF	407.56	334.22	2101.43	2476.28	359.83	130.89	130.89	130.89	130.89	130.89
LT_BP	181.67	165.00	145.00	865.00	226.00	62.00	158.00	158.00	158.00	438.00
LV_BP	93.00	45.00	45.00	928.00	226.00	29.00	154.00	154.00	154.00	534.00
LV_GR	93.00	45.00	45.00	928.00	226.00	29.00	154.00	154.00	154.00	534.00
PL_BP	343.98	140.49	351.09	974.63	334.17	97.00	245.82	245.82	245.82	509.44
RU_BP	181.67	165.00	145.00	865.00	226.00	62.00	158.00	158.00	158.00	438.00
RU_GF	181.67	165.00	145.00	865.00	226.00	62.00	158.00	158.00	158.00	438.00
SE_BB	254.06	198.77	71.81	3003.87	678.47	22.01	187.11	187.11	187.11	822.32
SE_BP	258.88	203.67	72.31	3003.87	678.47	22.01	187.22	187.22	187.22	777.91
SE_BS	257.27	202.04	72.14	3003.87	678.47	22.01	187.18	187.18	187.18	792.71
SE_DS	259.76	204.54	72.36	3003.87	678.47	22.01	187.11	187.11	187.11	778.84
SE_KT	258.88	203.67	72.31	3003.87	678.47	22.01	187.22	187.22	187.22	777.91

Table 13 Standard outputs for livestock classes and types

The SOs in table 3 can subsequently be aggregated to single representative livestock types by applying the weights of table 2. From this calculation we obtain a weighted average of the SOs for each drainage basin depending on the specific herd composition of the drainage basin. As such we calculate the value of the weighted average cow or pig in each drainage basin and consider this the cost of reducing a livestock type by one unit. The weighted SO calculation can be made by the following equation:

$$WSO_D^{Cattle} = \sum_L W_{L,D}^{Cattle} * SO_{L,D}^{Cattle}$$

$$WSO_D^{Pigs} = \sum_L W_{L,D}^{Pigs} * SO_{L,D}^{Pigs}$$

This weighted average determines the price of a unit reduction in one livestock type assuming that the relative composition of livestock classes within each type remains constant. The weighted SOs an thus the cost of livestock reduction are reported in table 4

WSO (weighted SO) €/representative animal		
	Cattle	Pigs
DE_BP	1121.90	255.83
DE_DS	1044.47	237.96
DK_BP	940.01	235.05
DK_DS	1064.12	245.90
DK_KT	1037.90	245.58
EE_BP	892.63	177.06
EE_GF	892.63	177.06
EE_GR	893.07	177.16
FI_BB	1411.18	130.89
FI_BS	1376.85	130.89
FI_GF	1394.50	130.89
LT_BP	470.33	161.19
LV_BP	624.11	167.41
LV_GR	473.67	161.02
PL_BP	735.49	223.09
RU_BP	559.91	155.66
RU_GF	469.48	160.18
SE_BB	1274.02	204.60
SE_BP	930.15	176.22
SE_BS	945.35	180.25
SE_DS	844.45	179.44
SE_KT	957.22	178.59

Table 14 Weighted SO for the two livestock types

2.3.4. Effectiveness calculations

A much similar method is applied to calculate the nitrogen and phosphate effect of a reduction. The same composition based weights from table 2 are applied but for this calculation the parameter of interest is excretion rates. Excretion rates for the two nutrients of interest per year per animal are supplied by Hong et al (2011). The excretion rates are supplied for each livestock class for each country and are reported in table 5 and 6.

Nitrogen excretion rates by livestock class (kgN/year/animal)										
	PC1_PC2	PC3100	PC3210	PC3221	PC3222	PP1000	PP2000	PP3000	PP4100	PP4200
DE	40.5	59	44	101	84	3.8	11	11	13	26
DK	58.1	54.9	61.8	110	73.3	2	6.2	16.3	23	25.7
EE	30	42	40	93	60	2	9	11	9	19
FI	31.8	40	40	105	55	5.6	9	11	9	19
LT	30	42	40	82	60	2	9	11	9	19
LV	30	42	40	86	60	2	9	11	9	19
PL	32.3	42	60	86	60	2.5	9	15	20	16
RU	30	42	40	76	60	2	9	11	9	19
SE	37.3	58	47	112	63	2.3	9	9	9	19

Table 15 Nitrogen excretion rates by livestock class

Phosphorus excretion rates by livestock class (kgP/year/animal)										
	PC1_PC2	PC3100	PC3210	PC3221	PC3222	PP1000	PP2000	PP3000	PP4100	PP4200
DE	6.75	9.83	7.33	16.83	14	1.267	3.67	3.67	4.33	8.67
DK	9.68	9.15	10.3	18.33	12.22	0.667	2.07	5.43	7.67	8.57
EE	5	7	6.67	15.5	10	0.667	3	3.67	3	6.33
FI	5.3	6.67	6.67	17.5	9.17	1.867	3	3.67	3	6.33
LT	5	7	6.67	13.67	10	0.667	3	3.67	3	6.33
LV	5	7	6.67	14.33	10	0.667	3	3.67	3	6.33
PL	5.38	7	10	14.33	10	0.833	3	5	6.67	5.33
RU	5	7	6.67	12.67	10	0.667	3	3.67	3	6.33
SE	6.22	9.67	7.83	18.67	10.5	0.767	3	3	3	6.33

Table 16 Phosphorus excretion rates by livestock class

Applying the weights to the excretion rates is done in a similar fashion to the SOs by the formula

$$WEX_D^{Cattle} = \sum_L W_{L,D}^{Cattle} * EX_{L,D}^{Cattle}$$

$$WEX_D^{Pigs} = \sum_L W_{L,D}^{Pigs} * EX_{L,D}^{Pigs}$$

This results in a weighted excretion measure *WEX* for each drainage basin *D* which is the reduction in N and P for a unit reduction of cattle or pigs by taking away the excretion of a unit of the representative average livestock type. The weighted excretion rates are reported in table 7 and 8.

Weighted N excretion (kg N/year/animal)		
	Cattle	Pigs
DE_BP	72.45	11.00
DE_DS	68.02	10.48
DK_BP	75.52	9.97
DK_DS	77.77	9.57
DK_KT	77.19	9.53
EE_BP	67.09	8.59
EE_GF	67.09	8.59
EE_GR	67.11	8.59
FI_BB	66.13	10.13
FI_BS	65.40	10.14
FI_GF	65.91	10.12
LT_BP	57.95	10.33
LV_BP	66.58	9.53
LV_GR	60.82	10.21
PL_BP	68.49	9.64
RU_BP	58.49	8.82
RU_GF	55.02	10.25
SE_BB	66.52	8.20
SE_BP	58.66	7.47
SE_BS	59.19	7.61
SE_DS	56.90	7.57
SE_KT	59.24	7.54

Table 17 Weighted N excretion for a representative animal

Weighted P excretion (kg P/year/animal)		
	Cattle	Pigs
DE_BP	12.07	3.67
DE_DS	11.34	3.50
DK_BP	12.58	3.32
DK_DS	12.96	3.19
DK_KT	12.86	3.18
EE_BP	11.18	2.86
EE_GF	11.18	2.86
EE_GR	11.19	2.87
FI_BB	11.02	3.38
FI_BS	10.90	3.38
FI_GF	10.99	3.37
LT_BP	9.96	3.44
LV_BP	11.09	3.18
LV_GR	10.14	3.40
PL_BP	10.02	3.21
RU_BP	9.75	2.94
RU_GF	9.17	3.42
SE_BB	11.09	2.73
SE_BP	9.78	2.49
SE_BS	9.87	2.54
SE_DS	9.49	2.52
SE_KT	9.88	2.51

Table 18 Weighted P excretion for a representative animal

The N and P reduction from livestock reduction is assumed to be a consequence of the reduced manure not being used for fertilisation at the fields. It is further assumed that farmers will substitute the reduced amount of manure with mineral fertiliser. The difference of the utilisation rates are thus the effective reduced amount of N and P. The N and P utilisation rates of manure are reported in table 9 and 10.

Manure utilisation rate for N (percent)	
DE_BP	50
DE_DS	50
DK_BP	70
DK_DS	70
DK_KT	70
EE_BP	50
EE_GF	50
EE_GR	50
FI_BB	70
FI_BS	70
FI_GF	70
LT_BP	50
LV_BP	50
LV_GR	50
PL_BP	50
RU_BP	50
RU_GF	50
SE_BB	70
SE_BP	70
SE_BS	70
SE_DS	70
SE_KT	70

Table 19 Manure utilisation rate in percent of N content

Manure utilisation rate for P (percent)	
DE_BP	90
DE_DS	90
DK_BP	90
DK_DS	90
DK_KT	90
EE_BP	90
EE_GF	90
EE_GR	90
FI_BB	90
FI_BS	90
FI_GF	90
LT_BP	90
LV_BP	90
LV_GR	90
PL_BP	90
RU_BP	90
RU_GF	90
SE_BB	90
SE_BP	90
SE_BS	90
SE_DS	90
SE_KT	90

Table 20 Manure utilisation rate in percent of P content

The difference of the utilised amount of N and P then proceeds through the retention chain before the effective reduction in the Baltic Sea is found as:

$$\Delta N_D^{EFF}(\Delta Cattle_D) = (1 - R_D^{SURF,Cattle})(1 - R_D^{GRW,Cattle}) * (1 - U_D^N) * WEX_D^{Cattle} * \Delta Cattle_D$$

$$\Delta N_D^{EFF}(\Delta Pigs_D) = (1 - R_D^{SURF,Pigs})(1 - R_D^{GRW,Pigs}) * (1 - U_D^N) * WEX_D^{Pigs} * \Delta Pigs_D$$

where R^{SURF} and R^{GRW} are drainage specific weighted surface water and groundwater retentions, U^N is the utilisation rate and *WEX* are the livestock type and drainage basin specific weighted excretions. A similar calculation is made for the reductions of P. The associated cost can be calculated as

$$Cost_D(\Delta Cattle_D) = WSO_D^{Cattle} * \Delta Cattle_D$$

$$Cost_D(\Delta Pigs_D) = WSO_D^{Pigs} * \Delta Pigs_D$$

As the costs and effects of livestock reduction both have a constant effect of *WSO* and *WEX* respectively, the cost function is linear which is also the case for the effective reduction function.

Annex 2.4. Restoring wetlands on agricultural soils (N & P abatement)

Authors: Hasler B., Göke C., Jørgensen S.L., Fonnesbedh-Wulff A., Smart J.C.R, Thodsen H..

This annex describes how wetland restoration at agricultural land are portrayed in the BALTCOST model for identifying the lowest cost combination of abatement measures for delivering specified reduction targets for nitrogen (N) and phosphorus (P) loads into 7 sea regions of the Baltic Sea. Restoration of wetlands is one of 5 abatement measures considered by the current version of BALTCOST.

The description of the wetland measure in BALTCOST proceeds in the following sequence:

- the wetland restoration measure
- methodology for estimating the costs
- data sources used in estimating the costs
- effects of restored wetlands on N and P loads into the river systems and thence into the receiving sea regions in the Baltic
- capacity for restoring wetlands

2.4.1. The wetland restoration measure

Wetland restoration has been an important measure to obtain nutrient reductions in both Denmark and Sweden, wetland restoration is for instance an important measure in both the Danish Action Plans for the Aquatic Environment (VMPII from 1998 and VMPIII from 2004) and in the Agreement on Green Growth from 2009, which partly implements the Water Framework Directive.

Wetland restoration is defined as a measure where wetlands are restored at agricultural areas that have been wet in the past. In this context we do not include construction of wetlands which is regarded as another measure than restoring wetlands, because the effects and costs of restored and constructed wetlands are different. Constructed wetlands are wetlands on non-agricultural land, often small ponds established to reduce the nutrient loads from agricultural sources and/or waste water as well as loadings from forests etc. The constructed wetlands incur construction costs as well as maintenance costs. The costs of implementing constructed wetlands has been collected in Sweden where this measure has been used during a period. Elofsson (2011) has estimated the costs of constructed wetlands, and these costs can be adjusted to all countries around the Baltic, but requires the estimation of the capacity limit for this measure, i.e. the upper limit of the acreage of this measure. It is not straight forward to estimate this constraint, and we have not yet succeeded in estimating a reliable capacity limit. This measure will thus be included in the model at a later stage when the problem of estimating the potential capacity has been solved, which require cooperation between drainage basin modellers, hydrologists and economists.

Opposite to the constructed wetlands restored wetlands are assumed implemented at agricultural land by discarding drainage or by implementing other hydrological changes that changes the land use from agricultural use to wetland. Some wetlands, e.g. grasslands that are occasionally wet, are also defined as wetland areas, i.e. wetlands are defined at a a gradient from occasionally wet grasslands to lakes. This means that the types of wetlands restored can become lakes, meadows, reed swamps and other areas close to watercourses. With discardment of drainage, termination of maintenance of watercourses and other hydrological changes permanent moist or occasionally moist areas that can reduce the nitrogen loss from agricultural soils are being recreated (Hansen et al 2011).

The effect of restoration of a lake area and a grassland will be different from each other, but in this implementation in the model we will not have the knowledge if the restoration will imply a lake or a grassland restoration. The effect is therefore uniform per hectare irrespective of the type of wetland.

2.4.2. Methodology and cost estimations

The cost calculations that determine the cost of wetland restoration are, just like the livestock reduction measure, based on the estimated opportunity costs. Even if construction and maintenance costs can be relevant for restored wetlands just as they are for constructed wetlands it is chosen to estimate the costs as the opportunity costs. Hereby we are using the detailed information available on the crop structure in the drainage basins

For determining the costs of wetland restoration on one hectare we use the standard output (SO) of crop grown in each of the drainage basins, which is obtained from EuroStat (see table 2.4.1.). The SOs of each crop are reported in table 1. Just as for livestock reduction we have used the SO from the most fitting NUTS regions compared to the drainage basins for which the SO data is available (e.g. DE_BP is SO for Mecklenburg Vorpommern while DE_DS is an average of SOs from Mecklenburg Vorpommern and Schleswig-Holstein, see table 2.4.2.). For Russia where no SO data is available we have used Lithuanian values, solely based on geographical arguments.

The SOs in table 2.4.1 can subsequently be aggregated to an average crop SO for each drainage basin by applying the weights of table 2.4.3., and the average SO of an agricultural hectare is the opportunity cost of one hectare of wetland.

Weighted SO for finding the opportunity cost of one average hectare in each drainage basin are estimated with formula 2.4.1.:

$$(2.4.1)\ WSO_D = \sum_c SO_{c,D} * SA_{c,D}$$

Where $SO_{c,D}$ is standard output of crop c in drainage basin D and $SA_{c,D}$ is crop c's share of the area in the drainage basin.

This share is calculated as (2.4.2.):

$$(2.4.2.)\ SA_{c,D} = \frac{A_{c,D}}{\sum_c A_{c,D}}$$

This weighted SO is the opportunity cost of taking an average hectare in the drainage basin out of agricultural production. If HW_D is the hectares of wetland in drainage basin D the cost function for wetlands is:

$$(2.4.5.)\ Cost_D = WSO_D * HW_D$$

Table 2.4.1.Standard Ouputs for arable crops, Eurostat, 2005.

	BARL	FALL	GRAE	GRAI	MAIF	OATS	OFAO	OFAR	POTA	PULS	RAPE	RYEM	SUGB	SWHE
DE_BP	851,99	100,00	129,04	374,84	879,85	656,67	447,48	406,89	2.794,68	631,39	993,96	702,02	2.526,68	969,20
DE_DS	958,55	100,00	129,04	424,20	902,17	742,04	449,22	449,41	3.031,26	735,91	1.081,82	806,29	2.662,71	1.107,61
DK_BP	704,54	0,00	338,72	338,72	888,87	603,34	888,87	888,87	4.545,17	614,81	812,14	590,21	2.923,03	889,64
DK_DS	656,72	0,00	338,72	338,72	888,87	599,06	888,87	888,87	3.647,33	559,64	812,14	573,12	2.693,91	847,51
DK_KT	608,90	0,00	338,72	338,72	888,87	594,78	888,87	888,87	2.749,48	504,47	812,14	556,03	2.464,79	805,38
EE_BP	248,00	0,00	1,00	111,00	492,00	200,00	214,00	236,00	2.137,00	212,00	340,00	207,00	0,00	284,00
EE_GF	248,00	0,00	1,00	111,00	492,00	200,00	214,00	236,00	2.137,00	212,00	340,00	207,00	0,00	284,00
EE_GR	248,00	0,00	1,00	111,00	492,00	200,00	214,00	236,00	2.137,00	212,00	340,00	207,00	0,00	284,00
FI_BB	333,38	0,00	98,69	411,07	594,62	262,90	594,62	640,72	3.032,60	309,82	257,14	249,33	1.688,37	428,27
FI_BS	333,38	0,00	98,69	411,07	594,62	262,90	594,62	640,72	3.032,60	309,82	257,14	249,33	1.688,37	428,27
FI_GF	333,38	0,00	98,69	411,07	594,62	262,90	594,62	640,72	3.032,60	309,82	257,14	249,33	1.688,37	428,27
LT_BP	289,00	0,00	9,00	69,00	319,00	172,00	163,00	77,00	1.318,00	282,00	371,00	205,00	1.740,00	383,00
LV_BP	223,00	2,00	10,00	21,00	30,00	180,00	30,00	30,00	1.346,00	236,00	359,00	201,00	1.393,00	330,00
LV_GR	223,00	2,00	10,00	21,00	30,00	180,00	30,00	30,00	1.346,00	236,00	359,00	201,00	1.393,00	330,00
PL_BP	296,67	0,00	50,81	375,34	596,66	205,28	357,89	300,84	1.191,34	447,29	483,49	190,55	1.545,14	380,51
RU_BP	289,00	0,00	9,00	69,00	319,00	172,00	163,00	77,00	1.318,00	282,00	371,00	205,00	1.740,00	383,00
RU_GF	289,00	0,00	9,00	69,00	319,00	172,00	163,00	77,00	1.318,00	282,00	371,00	205,00	1.740,00	383,00
SE_BB	182,31	0,00	52,20	71,16	1.190,11	187,76	719,23	381,74	2.885,63	310,90	351,33	343,92	2.191,25	329,10
SE_BP	349,81	0,00	81,62	128,59	1.190,11	327,58	850,00	573,97	4.436,66	381,63	466,41	425,38	2.311,01	551,68
SE_BS	293,97	0,00	71,81	109,44	1.190,11	280,97	806,41	509,89	3.919,65	358,05	428,05	398,23	2.271,09	477,49
SE_DS	400,04	0,00	81,73	159,86	1.190,11	361,14	850,00	588,24	4.667,14	300,44	512,83	493,11	2.430,77	591,18
SE_KT	349,81	0,00	81,62	128,59	1.190,11	327,58	850,00	573,97	4.436,66	381,63	466,41	425,38	2.311,01	551,68

Missing value: 0 inserted

Standard Output (SO) replaces SGM (SGM is the value of output from one hectare or one animal - cost of variable inputs required to produce that output).

In Eurostat SO is defined as the monetary value of the gross agricultural output at the farm-gate price.

Table 2.4.2. Assumption on standard output origin for the drainage basins

DE_BP	Mecklenburg Vorpommern
DE_DS	Avg. of Mecklenburg Vorpommern and Schleswig-Holstein
DK_BP	DK Øerne
DK_DS	Avg. of Jylland and Øerne
DK_KT	DK Jylland
EE_BP	EE same value for whole country
EE_GF	EE same value for whole country
EE_GR	EE same value for whole country
FI_BB	FI same value for whole country
FI_BS	FI same value for whole country
FI_GF	FI same value for whole country
LT_BP	LT same value for whole country
LV_BP	LV same value for whole country
LV_GR	LV same value for whole country
PL_BP	PL avg. value. only one catchment
RU_BP	Values for LT used
RU_GF	Values for LT used
SE_BB	Mellersta Norrland/Övre Norrland
SE_BP	Avg. of Stockholm/Östra Mellansverige/Sydsverige/Västsverige and Norra Mellansverige/Smaland med öarna
SE_BS	Avg. of all Swedish regions.
SE_DS	Stockholm/Östra Mellansverige/Sydsverige/Västsverige
SE_KT	Avg. of Stockholm/Östra Mellansverige/Sydsverige/Västsverige and Norra Mellansverige/Smaland med öarna

Table 2.4.3. Area weigthed standard outputs: The costs of restoring wetlands in each drainage basin

Area weighted SO

	WSO
DE_BP	754
DE_DS	874
DK_BP	904
DK_DS	846
DK_KT	683
EE_BP	269
EE_GF	265
EE_GR	274
FI_BB	497
FI_BS	428
FI_GF	407
LT_BP	333
LV_BP	190
LV_GR	186
PL_BP	445
RU_BP	343
RU_GF	211
SE_BB	331
SE_BP	447
SE_BS	408
SE_DS	761
SE_KT	456

The average costs of restoring wetlands, measured as the opportunity costs, are apparent from table 2.4.3., and are the costs implemented in the current version of BALTCOST.(8,.0)

2.4.3. Estimated effect of wetland restoration on nitrogen and phosphorus leaching

It is assumed that 1 ha of restored wetlands retains 150 kg of N loadings, and 0.7 kg of P to surface waters.. This effect is used when agricultural land is converted to a wetland. For constructed wetlands the effect on the N retention will be larger, and is assumed to be 300 kg N /ha/ye, and 1,4 P/ha/yr. The effects follow the analysis of Hoffmann et al. (2006, tables 3.28 and 3.29).

The N and P effects for constructed wetlands are conservative expert judgements based on (i) Hoffman et al's Danish data from restored wetlands and (ii) Swedish data from constructed wetlands. The reported Swedish rates for constructed wetlands are respectively 900 kg N/ha/yr and 18 - 48 kg P/ha/yr (no. of observations is 50, pers. comm. C.C. Hoffmann). We suggest estimates in the low end of this range formed by the Danish and Swedish data since higher rates demands very high nutrient concentrations in the input water to the constructed wetland which cannot be expected everywhere in the Baltic Sea drainage basin.

2.4.4. Estimated capacity for wetland restoration

Data and Methods

The method used to identify areas that have potential for restoring wetlands assumes that these areas have been wetlands in the past, before the agricultural areas were drained. An additional criterion to estimate the capacity is that only agricultural areas are suitable for this type of measure where the effects and costs estimations are built on the assumption that wetlands are restored on agricultural land.

Soil Data

National datasets were used for Sweden and Denmark, for all other countries the Harmonized World Soil Database (HWSD v 1.1) was used to identify areas with organic soils. The HWSD 1:1 mill. is based on the European Soil database (ESDB). Compared to the ESDB the resolution is less detailed, but there are data gaps in the FAO 90 code in the ESDB which are filled in the HWSD dataset. All areas which fall in the group histosols were chosen. Their distribution is shown in Figure 2.1.

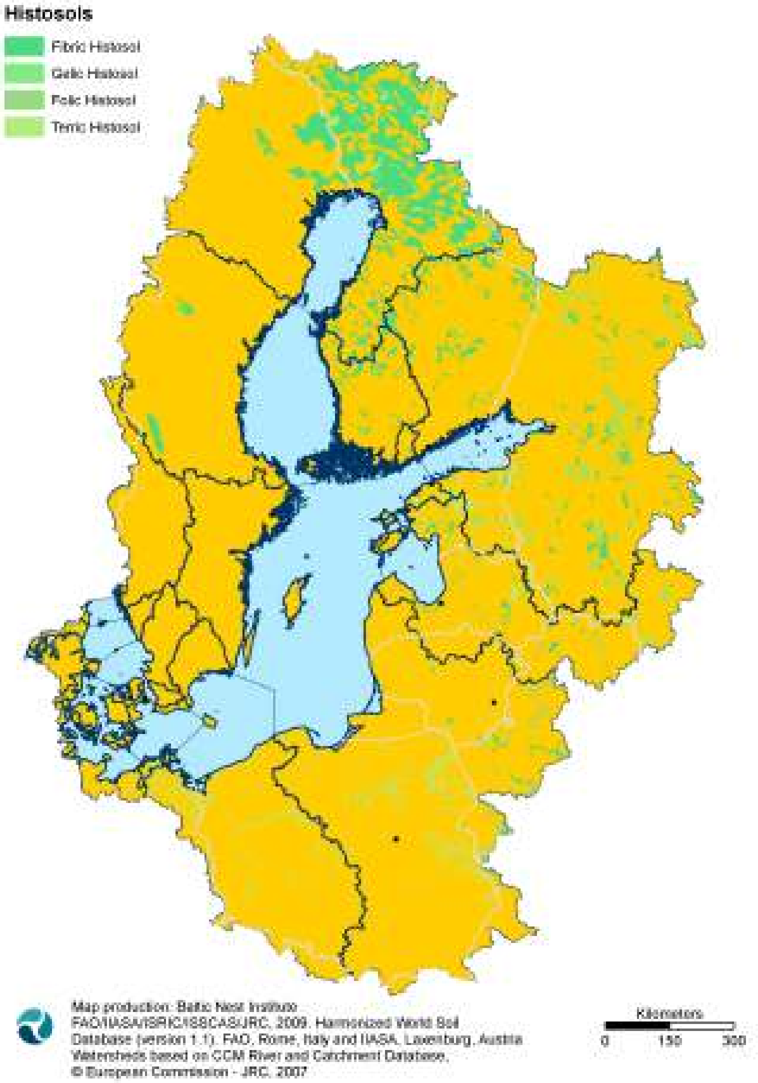

Figure 2.4.5: Distribution of histosols in the Baltic Sea drainage area (HWSD)

The scale of the HWSD means that little detail can be shown in the dataset. Small areas are therefore neglected and big connected areas are overestimated in the dataset. National datasets were therefore taken where available.

For Denmark the soil type of the Danish soil classification has been used. The source has the scale 1:25000 and does not include forest and urban areas from the investigation period 1975 – 79. Humus soils which contain more than 10 weight-% of humus in the surface soil were selected as indicator for potential wetlands. Figure 2.4.2

The Swedish data on quaternary deposits from the Geological Survey of Sweden has a scale of 1:1 million and is strongly generalized. Even though it has the same scale, the database differs from HWSD. It contains more fine structures, e.g. more small peat locations. Peat was defined as suitable for potential wetlands.

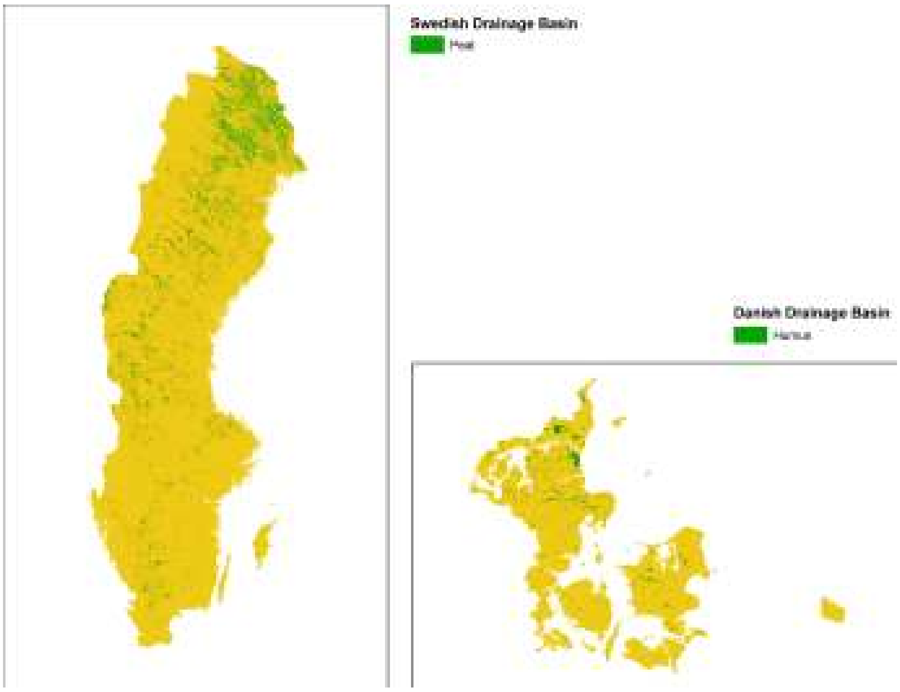

Figure 2.4.2 Distribution of humus soils and peat locations from national soil datasets

Landuse data

Corine Landcover 2000 and Global Landcover 2000 have been used to determine the actual land use within the area of EU 27 and outside EU 27 (BY, RU, UA) respectively.

Only land use classes indicating agricultural use have been categorized as suitable for the measure of creating wetlands. For the area covered by Corine Landcover all subclasses of the Level 1 category “Agricultural areas” have been chosen, for Global Landcover the classes containing cultivated areas or cropland, Table 2.4.4.. Not all classes of table 2.4.6. are occurring in the Baltic Sea drainage area.

Table 2.4.4. Agricultural land types

Source	CLC code	Description
CLC	211	Non-irrigated arable land
CLC	212	Permanently irrigated land
CLC	213	Rice fields
CLC	221	Vineyards
CLC	222	Fruit trees and berry plantations
CLC	223	Olive groves
CLC	231	Pastures
CLC	241	Annual crops associated with permanent crops
CLC	242	Complex cultivation patterns
CLC	243	Land principally occupied by agriculture, with significant areas of natural vegetation
CLC	244	Agro-forestry areas
GLC		Cultivated and managed areas
GLC		Mosaic: Cropland / Tree Cover / Other natural vegetation
GLC		Mosaic: Cropland / Shrub and/or grass cover
GLC		Irrigated Agriculture

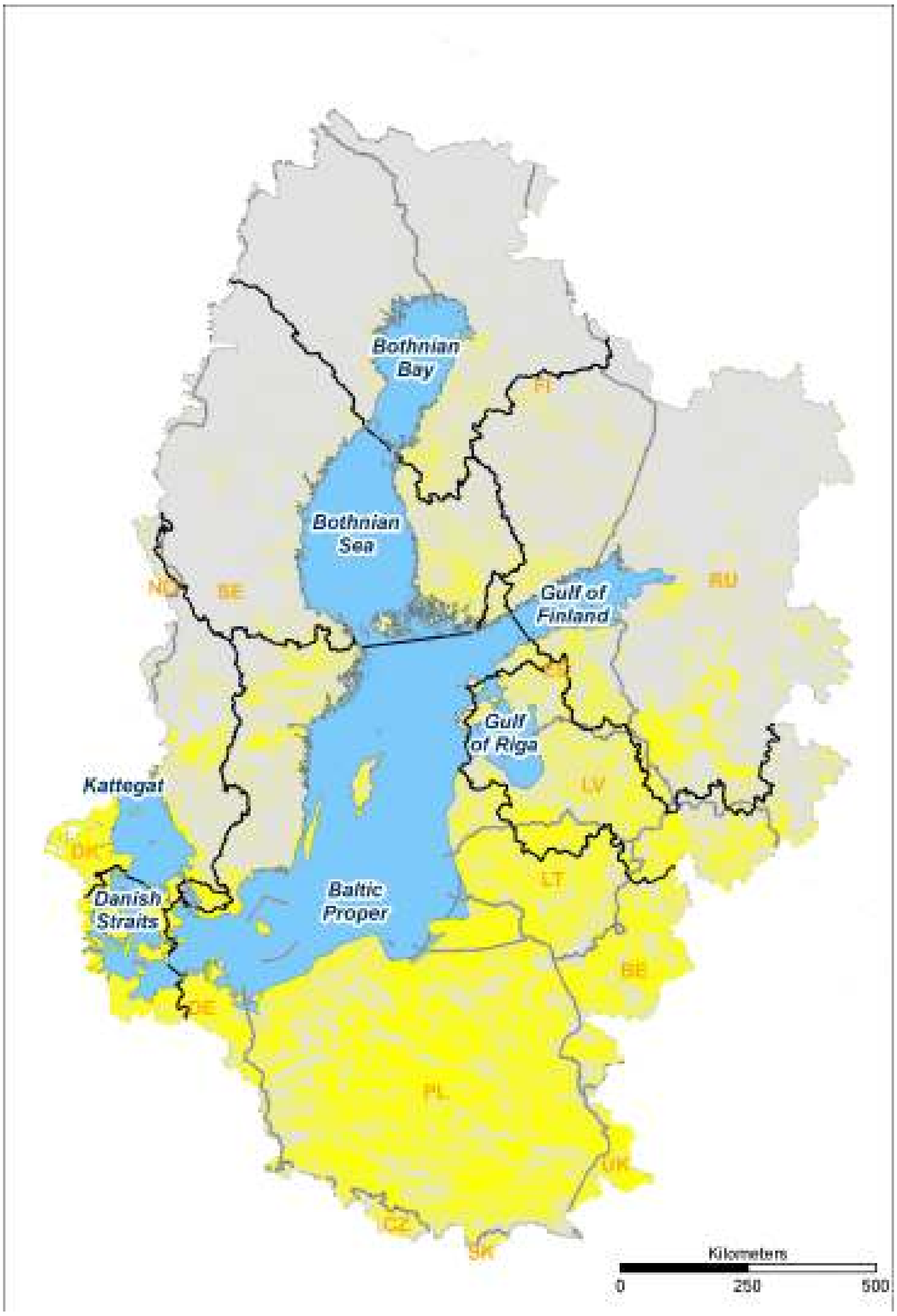

Figure 6 4.5. Extent of the agricultural area

2.4.5. Estimated capacities

For the total drainage basin of the Baltic Sea, 1.69 % of the area has been estimated to have a potential for setting up wetlands as a measure for nutrient retention. The potential wetlands are irregularly distributed over the drainage basin, for the distribution over the countries see table 2.1 or annex 2 for more detailed information on the distribution in the different basins.

Table 2.4.6.Distribution of wetland potentials

Country	Potential wetlands [%]	[km²]	Country area in drainage basin [km²]
BY	4.74%	4190	88302
CZ	0.00%	0	7477
DE	8.84%	2557	28917
DK*	4.12%	1274	30902
EE	3.29%	1499	45533
FI	0.83%	2544	307892
LT	1.55%	1007	64931
LV	1.49%	959	64403
NO	0.00%	0	14210
PL	3.70%	11506	311167
RU	0.86%	2818	325862
SE*	0.22%	963	442893
SK	0.00%	0	2098
UA	2.19%	261	11907
Total	1.69%	29582	1746494

*national soil data used

The chosen method is a very simplified approach and it is expected that it is slightly underestimating the potential for wetland. For Denmark alternative approaches have already been tested or used. A dataset of historic areas of water meadows, marshlands, bogs and drained areas is used for finding potential wetlands (Danish expression "lavbund"). They are given a legal status in the municipalities that makes it possible to restore them as wetlands. Parts of these low lying areas are identified as potentially suitable as wetlands in the management plans. The used dataset is derived from a map from shortly after 1900.

A total of 3679 km² of these lowlands lie nowadays on agricultural land (dataset CLC) in the drainage area to the Baltic Sea. The average for Denmark is 11.9 % which is more than the double of the analysis with humus soils. But the areas are very uneven distributed. In the watersheds for Northern and Central Kattegat the potential would be 22.2% and 19.1 % of the watershed or 37.1 % and 24.1 % of the agricultural area.

Another approach tested in Denmark was the modeling of waterlevel rise at selected rivers. The approach requires a proper river network and expert knowledge. The result lies with 2522 km² or 8.2 % between the other results. Only the method to use waterlevel rise takes the connection of the wetlands to the flowing (surface) water to some extent into consideration.

Additionally, the results are dependent on the quality of the input data. Comparing the histosols for Sweden n the HWSD and the peat locations in the national dataset , differences can be clearly seen, even if the scale of the datasets is the same. This fact would be a good argument for only using one dataset with a harmonized approach, but such a dataset was not available. The HWSD/ESDB is composed of several national datasets which each have their own scales, methods and classification systems.

References:

Hoffmann, C.C., Baatrup-Pedersen, A., Jeppesen, E, Amsinck, S.L. & Clausen, P. 2006. Overvågning af Vandmiljøplan II Vådområder 2005. 129 pages. Faglig rapport fra DMU nr. 576. http://faglige-rapporter.dmu.dk. The N effect is calculated as the median value of 14 monitored restored wetlands (table 3.28).

2.4.5. Annex Wetland capacities for the 117 watersheds .

WS ID	Watershed	Potential Wetlands		Area of Water-shed [km^2]
		[%]	[km^2]	
1	Rickleån	0.02%	0.4	1800
2	Skellefte älv	0.05%	5.5	11411
4	Pite älv	0.01%	0.9	11402
5	Alterälven	0.01%	0.0	400
6	Lule älv	0.00%	1.1	24689
8	Kalix älv	0.07%	12.5	17522
10	Torne älv	0.16%	64.9	40224
12	Kemijoki	0.34%	179.0	52475
14	Iijoki	0.69%	98.5	14321
15	Kiiminkijoki	0.57%	21.7	3798
16	Oulujoki	0.55%	130.8	23971
21	Kokemäenjoki	0.73%	200.0	27386
24	Forsmarksån	0.34%	1.0	300
25	Dalälven	0.06%	16.0	28700
26	Gavleån	0.40%	9.5	2398
27	Ljusnan	0.03%	5.7	19987
28	Delångersån	0.00%	0.0	1800
29	Ljungan	0.02%	1.9	12076
31	Indalsälven	0.06%	16.5	26170
33	Ångermanälven	0.02%	6.8	31884
35	Ume älv	0.03%	7.2	26849
41	Kymijoki	0.43%	154.4	36300
42	Neva	0.63%	1757.2	280255
43	Vironjoki	0.10%	0.4	397
46	Narva	2.17%	1250.8	57557
47	Kelia	5.32%	42.5	800
61	Gauja	1.12%	98.5	8793
62	Daugava	1.95%	1654.4	84913
63	Lielupe	0.98%	176.3	18004
71	Råneälven	0.02%	0.9	4000
72	Töreälven	0.02%	0.1	400
80	Venta	0.55%	62.1	11393
83	Neman	3.72%	3568.5	95925
84	Pregolia	1.94%	247.8	12800
85	Vistula	4.19%	8127.0	194175
87	Odra	2.48%	2952.8	119084
91	Helge å	0.84%	38.8	4609
93	Mörrumsån	0.43%	14.6	3400
95	Lyckebyån	0.03%	0.3	800
96	Ljungbyån	0.46%	4.1	898
97	Emån	0.41%	18.4	4499
98	Botorpströmmen	0.23%	2.3	1000

99	Motala ström	0.60%	85.2	14200
100	Nyköpingsån	0.34%	14.5	4200
101	Norrström	0.75%	174.8	23300
103	Kasari	5.37%	170.3	3173
131	Simojoki	1.10%	33.0	2999
132	Kuivajoki	0.80%	10.5	1300
142	Rönne å	0.84%	15.1	1791
143	Lagan	0.46%	30.3	6614
145	Nissan	0.28%	8.5	2996
147	Ätran	0.89%	28.6	3200
149	Viskan	0.68%	16.2	2400
151	Göta älv	0.39%	198.8	51621
171	Siikajoki	2.97%	124.8	4200
172	Pyhäjoki	0.81%	30.6	3800
173	Kalajoki	0.28%	12.2	4400
174	Lestijoki	1.10%	11.0	1000
175	Perhonjoki	4.01%	100.3	2500
176	Ähtävänjoki	2.24%	89.1	3985
177	Lapuanjoki	4.37%	187.7	4300
178	Kyrönjoki	5.94%	296.8	4999
201	Laihianjoki	11.12%	66.7	600
202	Närpiönjoki	1.57%	15.7	1000
205	Isojoki	1.41%	15.6	1100
221	Eurajoki	0.63%	8.8	1400
222	Sirppujoki	0.00%	0.0	400
231	Aurajoki	3.32%	29.9	900
232	Paimionjoki	0.00%	0.0	1000
233	Uskelanjoki	0.00%	0.0	900
234	Kiskonjoki	0.00%	0.0	1096
250	Karvianjoki	2.00%	72.1	3595
341	Gideälven	0.02%	0.8	3400
342	Lögdeälven	0.00%	0.0	1575
343	Öreälven	0.07%	2.2	3200
401	Vantaanjoki	0.36%	7.5	2097
402	Mustijoki	0.00%	0.0	698
403	Porvoonjoki	0.00%	0.0	1300
404	Koskenkylänjoki	0.00%	0.0	900
405	Iilolanjoki	0.00%	0.0	397
601	Pärnu	5.59%	379.0	6783
602	Salaca	2.69%	94.3	3500
1011	Coast DE & Arkona Basin	11.78%	278.7	2366
1012	Coast DE & Bornholm Basin	15.67%	1674.1	10685
1013	Coast DE & Fehmarn Belt	3.34%	354.1	10617
2011	Coast DK & Arkona Basin	1.68%	27.8	1659
2012	Coast DK & Bornholm Basin	0.21%	1.2	581
2013	Coast DK & Southern Kattegat	4.78%	143.9	3011

2014	Coast DK & Samso Belt	2.48%	230.3	9280
2015	Coast DK & Fehmarn Belt	1.92%	56.0	2922
2016	Coast DK & The Sound	0.99%	4.5	449
2017	Coast DK & Northern Kattegat	5.75%	34.3	597
2018	Coast DK & Central Kattegat	6.24%	775.7	12435
3011	Coast EE & Baltic Proper	2.38%	103.8	4359
3012	Coast EE & Gulf of Finland	2.18%	131.6	6034
3013	Coast EE & Gulf of Riga	1.83%	97.5	5317
4011	Coast FI & Bothnian Bay	2.60%	261.7	10074
4012	Coast FI & Bothnian Sea	0.59%	70.3	11858
4013	Coast FI & Baltic Proper	0.45%	15.7	3491
4014	Coast FI & Gulf of Finland	0.32%	16.4	5142
5011	Coast LT & Baltic Proper	2.91%	39.1	1345
6011	Coast LV & Baltic Proper	2.40%	134.7	5604
6012	Coast LV & Gulf of Riga	1.53%	94.0	6126
7011	Coast PL & Bornholm Basin	5.70%	813.6	14283
7012	Coast PL & Baltic Proper	5.17%	565.7	10942
8011	Coast RU & Baltic Proper	0.31%	17.6	5644
8012	Coast RU & Gulf of Finland	0.63%	148.0	23426
9011	Coast SE & The Sound	0.76%	19.7	2594
9012	Coast SE & Arkona Basin	1.10%	15.3	1389
9013	Coast SE & Bornholm Basin	0.40%	23.0	5769
9014	Coast SE & Baltic Proper	0.23%	46.3	19975
9015	Coast SE & Bothnian Bay	0.14%	26.6	19371
9016	Coast SE & Bothnian Sea	0.25%	54.7	21534
9018	Coast North of Northern Kattegat	0.00%	0.0	485
9019	Coast SE & Northern Kattegat	0.00%	0.0	657
9020	Coast SE & Central Kattegat	0.83%	14.9	1781
9021	Coast SE & Southern Kattegat	0.24%	5.6	2307
	Total	1.69%	29578.8	1746494

Annex 2.5. Improving wastewater treatment (WWT) (N & P abatement) Estimating the cost of improving wastewater treatment around the Baltic Sea

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This annex describes how waste water treatment (WWT) costs are portrayed in the BALTCOST model for identifying the lowest cost combination of abatement measures for delivering specified reduction targets for nitrogen (N) and phosphorus (P) loads into 7 sea regions of the Baltic Sea. Improved waste water treatment is one of 6 abatement measures considered by BALTCOST.

The description of the WWT measure in BALTCOST proceeds in the following sequence:

- the improved WWT measure
- methodology for estimating the WWT cost function
- data sources used in estimating the WWT cost function
- effects of improved WWT on N and P loads into the river systems and thence into the receiving sea regions in the Baltic
- capacity for implementing WWT improvement

2.5.1.Improving WWT

WWT is typically classified, in order of increasing cleaning capability, as primary, secondary or tertiary level treatment. Classification of WWT plants (WWTPs) relates primarily to their capability to reduce the biological oxygen demand (BOD), chemical oxygen demand (COD) and concentration of suspended solids (SS) in the effluent discharged to the environment (EU UWWTD 2011). A WWTP's ability to reduce N and P nutrient concentrations in discharge effluent also typically increases as treatment level increases, but this is dependent on the inclusion of specific nutrient removal processes within the treatment system. Nitrogen is typically removed by aerobic biological nitrification (oxidation of ammonia to nitrite NO_2^- which is then oxidized again by in a second stage facilitated by a different type of bacteria to produce nitrate NO_3^-) followed by anoxic biological denitrification (reduction of nitrate NO_3^- to produce gaseous nitrogen N_2 which is released to the atmosphere) assisted by introduction of methanol or an input stream of raw wastewater (US EPA 2004). Phosphorus can also be removed biologically, but is more usually removed by chemical precipitation following the addition of ferric chloride, aluminium or lime to assist coagulation and sedimentation as a separate 'chemical' flocculation stage in WWT (US EPA 2004).

In the BALTCOST context, improving WWT is regarded as the connection of an additional individual (or 'person equivalent' (PE) pollution load) to a higher level of WWT than that to which they are currently connected. Since the combined requirements of the Urban Wastewater Treatment Directive (EU UWWTD 1991) and the Water Framework Directive (EU WFD 2000) effectively imply that WWT throughout the EU will ultimately have to be upgraded to tertiary level, in BALTCOST we consider three potential upgrades to WWT (Table 1).

Table 1. Potential upgrades in WWT

Upgrade	From	To
A	No WWT	Tertiary WWT
B	Primary WWT	Tertiary WWT
C	Secondary WWT	Tertiary WWT

2.5.2. Translog cost function approach using Danish data

2.5.2.1 Methodology

A translog cost function analysis of a panel of 28 data cases detailing the annual operating and maintenance costs and annual infrastructure re-investment expenditures of Danish wastewater treatment (WWT) companies over the period 2006 – 2008 was used to establish the total cost of providing tertiary level WWT as a function of the annual incoming biological oxygen demand (BOD) load treated (in person equivalents (PEs) of annual BOD emissions) and the cost of electricity and labour as two major factor inputs to the WWT production process. The following explanation draws heavily on the presentation by Christensen & Greene (1976), with mathematics support from Renshaw (2009) and Snyder & Nicholson (2008).

The cost function and the production function approaches are duals in microeconomic analyses of the structure of production, production efficiency and costs (Diewert, 1974). The specification of a particular production function thus implies a particular cost function and vice versa. Christensen & Greene recommend direct estimation of the production function when the level of production of the output good is endogenous in the firm's profit maximisation (or cost minimisation) problem, or direct estimation of the equivalent cost function when the level of output production is exogenous to the firm's production problem (Christensen & Greene, 1976). WWT companies operate in a heavily regulated business environment where they are obliged to supply WWT services to however many customers wish to be connected to the WWT system, and, typically, are required to supply those WWT services at closely regulated prices. The level of output produced – i.e. the total volume of wastewater treated – and the unit price which can be charged for that output are therefore essentially exogenous to the firms' business decisions. WWT firms cannot adjust the quantity of WWT supplied in order to maximise profits, but must instead adjust their mix of inputs (labour, capital re-investment, consumables and maintenance expenditures) to minimise their costs, and thus maximise their profits, given the quantity of WWT they are required to provide and the prices which they are allowed to charge for WWT services. Following Christensen & Greene's advice, here we estimate the parameters within a transcendental logarithmic ('translog') cost function from the available data on short time panel of cost and production data from WWT companies in Denmark.

The cost function uses the incoming BOD load (in PE), and the prices of labour and electricity inputs to the operation and maintenance of WWTPs and to re-investment in WWT infrastructure as the (exogenous) arguments against which the parameters of a translog-form cost function are estimated, knowing each firm's expenditure on the different inputs when, we assume, the firms are attempting to minimise the total costs incurred in delivering the required (exogenous) volume of wastewater treated. The WWT industry competes with the rest of the economy for the inputs it requires. It is therefore reasonable to regard prices for these inputs as exogenous, i.e. not influenced by the input demands of the WWT firms.

The estimated translog cost function takes the form shown in Eqn 1, which allows for the incoming BOD load (in PE) and the prices of labour and electricity to influence the (assumed minimised) total cost of delivering WWT linearly, quadratically and via second order interaction terms:

$$\ln(TC) = \alpha_0 + \alpha_Y \ln Y + \beta_e \ln P_e + +\beta_l \ln P_l + \frac{1}{2}\delta_{YY}(\ln Y)^2 + \frac{1}{2}\gamma_{ee}(\ln P_e)^2 + \frac{1}{2}\gamma_{ll}(\ln P_l)^2$$
$$+ \gamma_{el} \ln P_e \ln P_l + \rho_{Ye} \ln Y \ln P_e + \rho_{Yl} \ln Y \ln P_l \qquad (1)$$

where:
TC = total annual cost of WWT (in Danish krone (1 Danish krone = 7.456 Euro): includes all expenditures on operation & maintenance, infrastructure renewals and reinvestment)
Y = total annual input BOD load in PE (1 PE = 21.9 kg BOD per year)
P_e = price of electricity as an input to production (standardised to 1.01 kr / kWh)
P_l = price of labour as an input to production (standardised to 415949 kr / annual FTE)
ln denotes natural logarithm
$\alpha, \beta, \delta, \gamma, \rho$ are the parameters estimated

Estimation of the translog parameters is assisted by following Christensen & Greene (1976) in applying Sheppards's Lemma[2] to show that the partial derivatives $\frac{\partial \ln TC}{\partial \ln P_i}$ report the share of total cost attributable to factor input *i.* The resulting cost share equations (2 & 3) can therefore be estimated together with the original translog expression as a system of 'seemingly unrelated regressions' (SURs) with appropriate cross-equation restrictions applied to the parameters to reduce the dimensionality of the problem and to enable the cost share data to be used in addition to the input expenditures and WWT scale to improve the efficiency of parameter estimation.

$$\frac{\partial \ln TC}{\partial \ln P_e} = S_e = \beta_e + \gamma_{ee} \ln P_e + \gamma_{el} \ln P_l + \rho_{Ye} \ln Y \qquad (2)$$

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[2] Sheppard's lemma states that, for the cost minimising combination of input factors to production $\frac{\partial TC}{\partial P_i} = x_i$ = derived demand for input *i*. Hence:

$\frac{\partial \ln TC}{\partial \ln P_i} = \frac{\partial TC}{\partial P_i} \cdot \frac{P_i}{TC} = \frac{x_i P_i}{TC} = S_i$ = share of total costs attributable to input *i*.

$$\frac{\partial \ln TC}{\partial \ln P_l} = S_l = \beta_l + \gamma_{ll} \ln P_l + \gamma_{el} \ln P_e + \rho_{Yl} \ln Y \qquad (3)$$

where S_e and S_l denote the share of total costs attributable to electricity and labour, respectively, and all other symbols are as previously defined.

Since the cost shares sum to one, one of the cost share equations must be dropped to prevent overspecification. This can be achieved without losing the ability to estimate parameters relating to the 'dropped' input factor if the price of that factor is used as a numeraire for the price of the remaining input factor(s) and the dependent variable (here, the (natural log of the) total cost of delivering WWT). This produces the normalised system of Eqns 4 & 5, where the standardised labour price is the numeraire and the labour cost share equation is dropped from the SUR set:

$$\ln\left(\frac{TC}{P_l}\right) = \alpha_0 + \alpha_Y \ln Y + \beta_e \ln\left(\frac{P_e}{P_l}\right) + \frac{1}{2}\delta_{YY}(\ln Y)^2 + \frac{1}{2}\gamma_{ee}\left(\ln\left(\frac{P_e}{P_l}\right)\right)^2 + \rho_{Ye} \ln Y \ln\left(\frac{P_e}{P_l}\right) \qquad (4)$$

$$\frac{\partial \ln\left(\frac{TC}{P_l}\right)}{\partial \ln\left(\frac{P_e}{P_l}\right)} = S_e = \beta_e + \gamma_{ee} \ln\left(\frac{P_e}{P_l}\right) + \rho_{Ye} \ln Y \qquad (5)$$

Normalisation of the prices of other input factor(s) and the total cost to the numeraire imposes linear homogeneity in input prices on the production system (Brown *et al.* 1979). Linear homogeneity in input prices is a necessary condition of the assumed cost minimising behaviour of the WWT firms: if the costs of all inputs increased by the same proportion then the total cost of providing a given quantity of WWT would rise by the same proportion. If this were not the case it would imply that costs could be decreased further by adjusting the input mix, thus implying that the original mix was not actually cost minimising. Referring back to the non-normalised translog cost expression (1), linear homogeneity in input prices requires:

$$\sum_i \beta_i = 1; \qquad \sum_i \sum_j \gamma_{ji} = 0; \qquad \sum_i \rho_{yi} = 0 \qquad (6)$$

Given that linear homogeneity in input prices is enforced by normalisation, parameters relating to the normalising input factor can be recovered from the parameter estimates for the normalised system (Eqns 4 & 5) and the linear homogeneity restrictions (Eqns 6) (see Annex for details). Specifically:

$$\beta_l = 1 - \beta_e; \qquad \rho_{Yl} = -\rho_{Ye}; \qquad \gamma_{ll} = \gamma_{ee} = -\gamma_{el} \qquad (7)$$

This imposition of linear homogeneity in input prices is the only assumption which is enforced via the translog cost estimation. Other features of the production system such as homotheticity and/or homogeneity of the underlying production process, own-price and cross-price elasticities of demand, and elasticities of total cost with respect to scale and the prices of input factors can be tested or estimated from the empirical results. The underlying production process will be homothetic with regard to factor inputs if:

$$\rho_{Yi} = 0 \forall i \qquad (8)$$

whereas the underlying production process will be homogeneous with regard to its factor inputs[3] if:

$$\rho_{Yi} = 0 \forall i \text{ and } \delta_{YY} = 0 \qquad (9)$$

Own price elasticities of demand for the factor inputs are given by:

$$\varepsilon_{x_i,P_i} = \frac{\gamma_{ii}}{S_i} + S_i - 1 \qquad (10)$$

The elasticities of total cost with respect to output scale and the prices of the input factors are given by:

$$\varepsilon_{TC,Y} = \frac{\partial \ln TC}{\partial \ln Y} = \alpha_Y + \delta_{YY} \ln Y + \rho_{Ye} \ln P_e + \rho_{Yl} \ln P_l \qquad (11)$$

$$\varepsilon_{TC,P_e} = \frac{\partial \ln TC}{\partial \ln P_e} = S_e = \beta_e + \gamma_{ee} \ln P_e + \gamma_{el} \ln P_l + \rho_{Ye} \ln Y \qquad (12)$$

$$\varepsilon_{TC,P_l} = \frac{\partial \ln TC}{\partial \ln P_l} = S_l = \beta_l + \gamma_{ll} \ln P_l + \gamma_{el} \ln P_e + \rho_{Yl} \ln Y \qquad (13)$$

Homogeneity and homotheticity in production can be tested empirically across the dataset as these properties are established solely from estimated parameters. The elasticities must, however, be calculated separately for each data case as these are determined from estimated parameters in combination with firm-specific data on output scale, input prices and cost shares, as appropriate. Own-price elasticities of demand should be negative – a firm would be expected to use less of an input in its cost minimising input mixture, ceteris paribus, if the price of that input increased – and this is frequently used as a test of the validity of the results from the SUR regression.

Results will be presented for parameter estimation from the normalised SUR system (Eqns 4 & 5), together with firm-specific estimates of own-price elasticities of demand

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[3] Note that homogeneity of the production process with regard to the *quantities* of the factor inputs is a different property from linear homogeneity of the (minimised) cost function with regard to the *prices* of the input factors which was imposed by normalisation.

and the elasticities of total cost with respect to output scale and the prices of labour and electricity as input factors.

2.5.1.2 Results

The translog cost function (4), normalised to the price of labour, and the similarly normalised cost share equation for electricity input (5) were estimated as a set of seemingly unrelated regressions with cross equation equality constraints on the parameters $\beta_e, \gamma_{ee}, \rho_{Ye}$ using the SURE maximum likelihood estimation procedure in Limdep v9.0. The results obtained are shown in Table 1.

Table 1: Estimated parameters for the translog WWT cost fucntion and cost share equation for electricity input to WWT, normalised to the price of labour, estimated as a SURE system with appropriate cross-equation constraints. SURE maximum likelihood estimation on 28 data points. Loglikelihood: 22.2126

Parameter	Estimate	p-value	Significance
α_0	65.4285	.0381	**
β_Y	-9.1805	.0874	*
β_e	0.4095	.0186	**
δ_{YY}	0.8712	.0559	*
γ_{ee}	0.0548	.0130	**
ρ_{Ye}	0.0354	.0154	**

The coefficient estimates of Table 2 are recovered via the imposition of linear homogeneity in input prices which is enforced by normalisation:

Table 2: Translog cost function parameter estimates recovered via imposing linearly homogeneity in input prices through normalisation

Parameter	Estimate	Recovery mechanism
β_1	0.5905	$1-\beta_e$
γ_{ll}	0.0548	$=\gamma_{ee}$
γ_{el}	-0.0548	$=-\gamma_{ee}$
ρ_{Yl}	-0.0354	$=-\rho_{Ye}$

These results indicate that the WWT production function is neither homothetic ($\rho_{Yi} \neq 0 \forall i$) nor homogeneous ($\rho_{Yi} \neq 0 \forall i$ and $\delta_{YY} \neq 0$). Own price elasticities of demand were calculated (10) for all 28 data cases (Table 3). These show the expected negative sign for all expect one data case.

Table 3: Price elasticities of demand for electricity and labour

WWT company	Year	Price elasticity of demand for electricity	Price elasticity of demand for labour
Ba	2008	-0.150	-0.531
He	2008	-0.104	-0.507
A	2008	-0.030	-0.301
O	2008	-0.104	-0.507
Hj	2008	-0.222	-0.517
Bo	2008	-0.095	-0.497
S	2008	-0.067	-0.448
F	2008	0.017	0.411
G	2008	-0.095	-0.497
E	2008	-0.085	-0.484
Ba	2007	-0.150	-0.531
F	2007	-0.011	-0.147
He	2007	-0.131	-0.526
O	2007	-0.048	-0.392
Bo	2007	-0.113	-0.515
Sv	2007	-0.067	-0.448
A	2007	-0.039	-0.352
G	2007	-0.131	-0.526
E	2007	-0.113	-0.515
Bo	2006	-0.141	-0.529
S	2006	-0.058	-0.423
He	2006	-0.141	-0.529
G	2006	-0.113	-0.515
Ba	2006	-0.113	-0.515
O	2006	-0.058	-0.423
A	2006	-0.058	-0.423
E	2006	-0.150	-0.531
F	2006	-0.020	-0.235

Elasticities of total cost with respect to scale (in input PE BOD load) and the prices of labour and electricity were also calculated for all 28 data cases and for a representative WWT company of average scale facing average input prices (Table 4).

Table 4: Elasticities of total cost of WWT with respect to output scale (in input PE BOD load) and the prices of labour (P_l) and electricity (P_e) as inputs

WWT company	Year	Elasticity of total cost wrt scale	Elasticity of total cost wrt P_l	Elasticity of total cost wrt P_e
Ba	2008	0.495	0.164	0.836
He	2008	0.459	0.176	0.824
A	2008	2.124	0.123	0.877
O	2008	1.799	0.138	0.862
Hj	2008	1.547	0.166	0.834
Bo	2008	0.924	0.186	0.814
S	2008	0.640	0.196	0.804
F	2008	1.527	0.157	0.843
G	2008	0.464	0.209	0.791
E	2008	1.725	0.155	0.845
Ba	2007	0.566	0.160	0.840
F	2007	1.337	0.144	0.856
He	2007	0.330	0.200	0.800
O	2007	1.741	0.139	0.861
Bo	2007	0.936	0.181	0.819
S	2007	0.465	0.198	0.802
A	2007	2.022	0.142	0.858
G	2007	0.462	0.212	0.788
E	2007	1.622	0.149	0.851
Bo	2006	-0.647	0.182	0.818
S	2006	-0.055	0.157	0.843
He	2006	0.484	0.162	0.838
G	2006	0.566	0.159	0.841
Ba	2006	0.519	0.165	0.835
O	2006	1.697	0.113	0.887
A	2006	1.939	0.104	0.896
E	2006	1.793	0.121	0.879
F	2006	1.412	0.151	0.849
Average WWT company		**1.032**	**0.161**	**0.839**

The estimated translog cost function provides a basis for estimating the total cost of delivering tertiary level WWT (in 2008 Danish krone), knowing the scale of the WWT operation (in input PE BOD load [with 1 PE = 21.9kg BOD annually]) and local prices for labour and electricity as inputs to the WWT process (with labour price standardised to 415949 Danish krone / FTE and electricity price standardised to1.01 Danish krone per kWh. Currency conversion rate: 1 Danish krone = 7.456 Euro).

2.5.3.Application of the Danish translog WWT cost function around the Baltic

The translog tertiary WWT cost function estimated from Danish data was applied individually to 117 watersheds (Table 5) around the Baltic (Figure 1) to produce a local estimate of the total cost and average cost of tertiary WWT. These 117 watersheds were grouped into 22 Drainage Basins (See table 3 in chapter 1, this report), each of which was associated with one of 9 Baltic littoral countries (see table 1, chapter 1, this report) and one of 7 Baltic Sea Regions (see Figure 1, chapter 1, this report). Drainage Basins contained between 1 and 16 separate watersheds. The following data were obtained for each of the 117 watersheds in order to apply the translog tertiary WWT cost function for that watershed:

- average size of tertiary WWT plant in watershed (in PE) [via Erik Smedberg from Eurostat (countries except Russia) & OECD (Russia) data on the percentage of national populations connected to primary secondary and tertiary WWT in combination with data from EEA (for all countries except Russia) and Helcom (for Russia) detailing number of tertiary WWT plants in watershed. Where the average size of tertiary WWTPs in a particular watershed was not known the average tertiary WWTP size across the other watersheds in the relevant Drainage Basin was used. The resulting estimated average WWTP sizes per watershed are shown in Table 5]

- electricity price (Table 6) (per kWh in 2008 Euro) [From Eurostat (2007) Table 4.9 p66, converted to 2007 Euro using Eurostat (2011a), inflated to 2008 Euro using Eurostat (2011b), then standardised to the Euro equivalent of 1.01 Danish krone/kWh for use in the estimated translog cost function. Electricity price for Russia in 2005 obtained from: RAO-UES (2005) Chapter 9.1 ‘Electricity price for industrial consumers’.]

- labour price (Table 7) (per FTE in 2008 Euro) [From OECD (2011) converted from national currencies to 2008 Euro using Eurostat (2011a), then standardised to the Euro equivalent of 415949 Danish krone/FTE before use in the translog cost function. Labour price for Russia obtained from Havlik (2010) Table 1 p4.]

- capacity for expanding tertiary WWT (Table 5). Calculated as the sum of the population sizes currently provided with primary and secondary WWT plus an estimate of the number of currently un-connected individuals who could feasibly be provided with municipal WWT based on a calculation of remoteness (See 2.1 below).

The resulting estimated average annual cost of providing tertiary WWT at an averaged sized tertiary WWT plant in each of the 117 watersheds (2008 Euros per PE treated) are shown in Table 9.

Table 5: For each of the 117 watersheds: (i) average size of tertiary WWT plants (PE treated), (ii) average cost (2008 Euros per PE treated) of operating the average sized WWT plant in each of the 117 watersheds as predicted by the translog cost function for tertiary WWT, (iii) expansion capacity for tertiary WWT (PE weighted by the level of improvement) [Weighting applied: improvement from no current WWT to tertiary WWT = 1, improvement from current secondary or primary WWT to tertiary WWT = 0.7]

Watershed ID	Watershed Name	Average size of tertiary WWTP (PE)	Average cost of tertiary WWT (2008 Euro per PE)	Expansion capacity for tertiary WWT (weighted PE)
1	Rickleån	0	75	691
2	Skellefte älv	3242	7857	7022
4	Pite älv	1661	78946	7332
5	Alterälven	0	75	616
6	Lule älv	2500	18403	3448
8	Kalix älv	9365	450	11257
10	Torne älv	4955	2225	20612
12	Kemijoki	10713	310	15276
14	Iijoki	2646	14091	4094
15	Kiiminkijoki	9828	373	1833
16	Oulujoki	8602	504	17496
21	Kokemäenjoki	17837	118	74717
24	Forsmarksån	0	75	546
25	Dalälven	12225	256	47381
26	Gavleån	36490	48	8571
27	Ljusnan	4361	3200	18372
28	Delångersån	6480	1086	1733
29	Ljungan	6100	1270	12306
31	Indalsälven	26049	72	23820
33	Ångermanälven	5981	1337	12207
35	Ume älv	8299	593	4714
41	Kymijoki	15857	144	68734
42	Neva	14455	50	2793253
43	Vironjoki	0	0	991
46	Narva	32277	15	339105
47	Kelia	4769	1325	16510
61	Gauja	21432	42	87307
62	Daugava	112063	12	1074024
63	Lielupe	35569	22	327049
71	Råneälven	0	75	2496
72	Töreälven	0	75	393
80	Venta	23038	38	234980
83	Neman	58846	20	2367073
84	Pregolia	23986	22	481124
85	Vistula	59615	23	9232399
87	Odra	41579	29	5833742
91	Helge å	17544	131	40839
93	Mörrumsån	15839	157	11494

95	Lyckebyån	4472	2976	3187
96	Ljungbyån	36070	49	3940
97	Emån	10212	372	17322
98	Botorpströmmen	0	0	0
99	Motala ström	19302	112	57635
100	Nyköpingsån	14478	185	13999
101	Norrström	55145	34	206984
103	Kasari	5055	1129	20887
131	Simojoki	9372	414	456
132	Kuivajoki	9372	414	482
142	Rönne å	9310	456	31814
143	Lagan	12149	259	33885
145	Nissan	10101	381	11246
147	Ätran	2612	15868	4823
149	Viskan	12763	235	6171
151	Göta älv	14392	187	119401
171	Siikajoki	0	0	6875
172	Pyhäjoki	1721	64276	6514
173	Kalajoki	6188	1131	11816
174	Lestijoki	5546	1511	1592
175	Perhonjoki	0	0	6475
176	Ähtävänjoki	1506	106477	14102
177	Lapuanjoki	6043	1203	8791
178	Kyrönjoki	11950	247	10107
201	Laihianjoki	22007	84	0
202	Närpiönjoki	0	0	6399
205	Isojoki	0	0	1415
221	Eurajoki	1083	394309	4927
222	Sirppujoki	0	0	4364
231	Aurajoki	36174	45	4854
232	Paimionjoki	8297	548	1967
233	Uskelanjoki	12150	239	6400
234	Kiskonjoki	0	0	3472
250	Karvianjoki	3924	4046	6097
341	Gideälven	0	75	40
342	Lögdeälven	15495	163	32
343	Öreälven	0	75	1546
401	Vantaanjoki	90686	24	4786
402	Mustijoki	19918	98	1780
403	Porvoonjoki	18596	110	6456
404	Koskenkylänjoki	0	0	3178
405	Iilolanjoki	55121	31	496
601	Pärnu	18835	66	35826
602	Salaca	0	565	27735
1011	Coast DE & BP	16125	222	24536
1012	Coast DE & BP	18941	170	79783
1013	Coast DE & DS	18542	176	51275
2011	Coast DK & DS	23236	92	112646
2012	Coast DK & BP	2568	18295	8348
2013	Coast DK & KT	6163	1348	107367
2014	Coast DK & DS	10605	374	104358

2015	Coast DK & DS	8357	636	33036
2016	Coast DK & DS	60332	35	13984
2017	Coast DK & KT	8811	563	12516
2018	Coast DK & KT	8156	674	171612
3011	Coast EE & BP	109709	16	55097
3012	Coast EE & GF	26760	40	58210
3013	Coast EE & GR	5847	766	29754
4011	Coast FI & BB	25716	67	20679
4012	Coast FI & BS	31125	53	35788
4013	Coast FI & GF	5558	1503	17085
4014	Coast FI & GF	180113	25	11771
5011	Coast LT & BP	153307	17	51889
6011	Coast LV & BP	18050	54	40056
6012	Coast LV & GR	7296	336	74042
7011	Coast PL & BP	16763	94	291621
7012	Coast PL & BP	60447	22	462957
8011	Coast RU & BP	0	8	211436
8012	Coast RU & GF	25662	20	1572898
9011	Coast SE & DS	48930	37	38748
9012	Coast SE & BP	70047	29	26483
9013	Coast SE & BP	24335	79	36272
9014	Coast SE & BP	47882	37	157173
9015	Coast SE & BB	32945	54	21341
9016	Coast SE & BS	33467	53	46875
9018	Coast SE & KT	2995	10116	3818
9019	Coast SE & KT	259204	33	2935
9020	Coast SE & KT	18619	119	7072
9021	Coast SE & KT	59819	32	19096

Table 6: Electricity prices (2008 Euro per kWh) in the 9 countries from Eurostat (2007) Table 4.9 p66. Converted to 2007 Euro using Eurostat (2011a), inflated to 2008 Euro using Eurostat (2011b). Electricity price for Russia in 2005 obtained from: RAO-UES (2005) Chapter 9.1 ‘Electricity price for industrial consumers’

Country	Electicity Price (Euro 2008/kWh)
DE	0.109
DK	0.072
EE	0.057
FI	0.057
LT	0.058
LV	0.049
PL	0.061
RU	0.034
SE	0.064

Table 7: Annual labour cost (2008 Euro per full time equivalent) in the 9 countries. From OECD (2011) converted from national currencies to 2008 Euro using Eurostat (2011a). Labour cost for Russia obtained from Havlik (2010), Table 1, p4.

Country	Annual Labour Cost (Euro 2008/FTE)
DE	46895
DK	51451
EE	11839
FI	47656
LT	11270
LV	9730
PL	10969
RU	5674
SE	47393

Table 8: Country-specific deflators to convert 2008 Euros to 2005 Euros (Eurostat 2011b)

Country	Price deflator from 2008 to 2005
DE	0.9364
DK	0.9296
EE	0.8196
FI	0.9409
LT	0.8340
LV	0.7380
PL	0.9247
RU	0.6772
SE	0.9449

2.5.4.Estimating the populations connected to primary, secondary and tertiary level WWT and the population of currently un-connected individuals who could feasibly be connected to municipal WWT for each of the 117 catchments

National population sizes were obtained from the HYDE dataset (History Database of the Global Environment) for 2005 (http://gcmd.nasa.gov/index.html), designated as urban or rural populations. These national populations were redistributed to a 10x10 km grid underlying the 117 watersheds and 22 drainage basins. The proportion of the total national populations connected to primary, secondary or tertiary level WWT were obtained from Eurostat and Helcom for all countries draining into the Baltic Sea (See data Annex 2.5.1.). For Russia, Belarus, Ukraine and Slovakia the allocation of the connected populations between primary, secondary and tertiary level treatment was based on expert judgment.

For each country the total number of people connected to WWT was calculated knowing the proportions of the national populations connected. These total numbers of connected individuals were then spatially distributed across the 10 x 10km grid cells. The distribution was made based on the assumption that the urban population, and individuals in grid cells with higher population densities, were more likely to have a municipal WWTP connection than individuals in rural grid cells and cells with lower population densities. Applying this principle separately to each country in turn, the urban grid cells were sorted in descending order of population density and were then classified as connected, starting with the grid cells with the highest population density, until either all of the known connected population had been distributed, or all of the urban grid cells had been allocated. If, for a particular country, the total connected population had not been reached when the total urban population had been assigned as described, then the rural population was allocated to WWT using the same mechanism, starting with the rural cells with the highest population densities. This procedure was repeated for each country.
A similar mechanism was used to distribute the populations connected, in sequence, to tertiary, secondary and primary level WWT in order of decreasing population density, starting with the urban population and then, if necessary, moving on to the rural population. Thus the population connected to tertiary level WWT was distributed first, across the urban (and then if necessary rural) grid cells with the highest population densities. The population connected to secondary level WWT was then distributed amongst the remaining grid cells, again in order of decreasing population density. Finally the population connected to primary level treatment was distributed by the same mechanism. The assumption here was that higher levels of WWT would be associated with larger aggregations of urban population. Once the population which was known to be connected to all levels of WWT had been distributed as described, the total number of individuals who were not currently connected to any level of municipal WWT could be calculated for each grid cell. These currently un-connected individuals were then divided into feasibly connectable and un-connectable populations based on the following GIS calculation of remoteness.

(a) The population density-driven WWT connection procedure was applied to the Polish population until a total of 5.4 million Poles remained unconnected to any form of municipal WWT – in accordance with data indicating that 5.4 million Poles will remain unconnected to municipal WWT after upgrading of Polish WWT infrastructure to satisfy the EU Urban Waste Water Directive (Council Directive 91/271/EEC of 21 May 1991 concerning urban waste water treatment as amended by Commission Directive 98/15/EC and Regulations 1882/2003/EC and 1137/2008/EC) .

(b) The distance between each Polish grid cell containing unconnected individuals and either the nearest known WWTP, or the nearest town with at least 10000 inhabitants, was calculated.

(c) The least remote Polish grid cell containing unconnected individuals was identified. This remoteness distance was used as the remoteness threshold between the feasibly connectable and un-connectable populations.

(d) For all Baltic littoral countries the distance between each grid cell containing currently unconnected individuals and, either, a known WWTP (from the Eurostat and Helcom data), or a town with a population of at least 10000 was calculated

(e) Populations in grid cells with a remoteness distance exceeding that determined in step

(c) above were deemed to be un-connectable, whilst populations in grid cells with a remoteness distance below the step (c) threshold were deemed to be feasibly connectable. The total feasibly connectable population of currently un-connected individuals was calculated in this way for each of the 117 watersheds.

2.5.5. Estimating average cost of improving WWT in each Drainage Basin

The total population within each of the 117 watersheds which could feasibly be upgraded to tertiary WWT thus comprised the sum of the three upgradeable populations:

$$\text{Total population upgradeable to tertiary treatment} = \text{currently un-connected population which is feasibly connectable to municipal WWT } (N_A) + \text{population currently connected to primary treatment } (N_B) + \text{population currently connected to secondary treatment } (N_C)$$

(14)

The Danish data from which the translog cost function for tertiary WWT was estimated indicate that approximately 30% of the total cost of tertiary WWT is incurred in transporting wastewater to the WWTP, whilst the remaining 70% of total cost is incurred in treating wastewater at the WWTP. Wastewater from populations currently connected to primary or secondary WWT is currently incurring the cost of transportation to a WWTP. These components of the total upgradeable population are therefore considered to incur only 70% of the per person average cost of tertiary WWT in the relevant watershed. The effective population size used to calculate the total cost incurred in providing the maximum capacity expansion for tertiary WWT in each of the 117 watersheds (Table 5) was therefore:

$$\text{Maximum capacity for upgrading to tertiary treatment (effective PE for cost calculation)} = N_A + 0.7(N_B + N_C) \qquad (15)$$

where:

N_A = maximum PE upgradable from no current WWT provision to tertiary WWT

N_B = maximum PE upgradable from primary WWT to tertiary WWT

N_C = maximum PE upgradable from secondary WWT to tertiary WWT

Data detailing the average cost of providing tertiary WWT (2008 Euros per PE deflated to 2005 Euros per PE using Eurostat (2011b)) and the maximum capacity for upgrading to tertiary WWT (effective PE for cost calculation) [Table 9] in the watersheds within a particular drainage basin were combined to produce continuous functions to describe the average cost of improving WWT in each of the 22 drainage basins as a function of the number of individuals upgraded to tertiary WWT. The procedure used was as follows:

(a) For those (18) drainage basins which comprised more than one watershed, it was assumed that WWT would be improved in each watershed in turn within the drainage basin *in ascending order of average cost*, with the maximum capacity for improvement being fully implemented in a particular watershed before moving on to the watershed with the next lowest average cost. This enabled the total cost of improving WWT (2005 Euros) in a particular drainage basin to be plotted against the additional capacity provided (PE) assuming that WWT is improved sequentially, by watershed, within the drainage basin in order of increasing average cost. The most appropriate linear, quadratic or power law functional forms were then fitted to these synthesised total cost data via OLS regression (Figure 2 – example for SE-BP). The functional forms estimated were:

linear: $TC = \alpha + \beta Y$ (16)

quadratic: $TC = \alpha + \beta Y + \gamma Y^2$ (17)

power law: $TC = \lambda Y^{\theta}$ estimated as: $\ln TC = A + \theta \ln Y$ with $A = \ln \lambda$ (18)

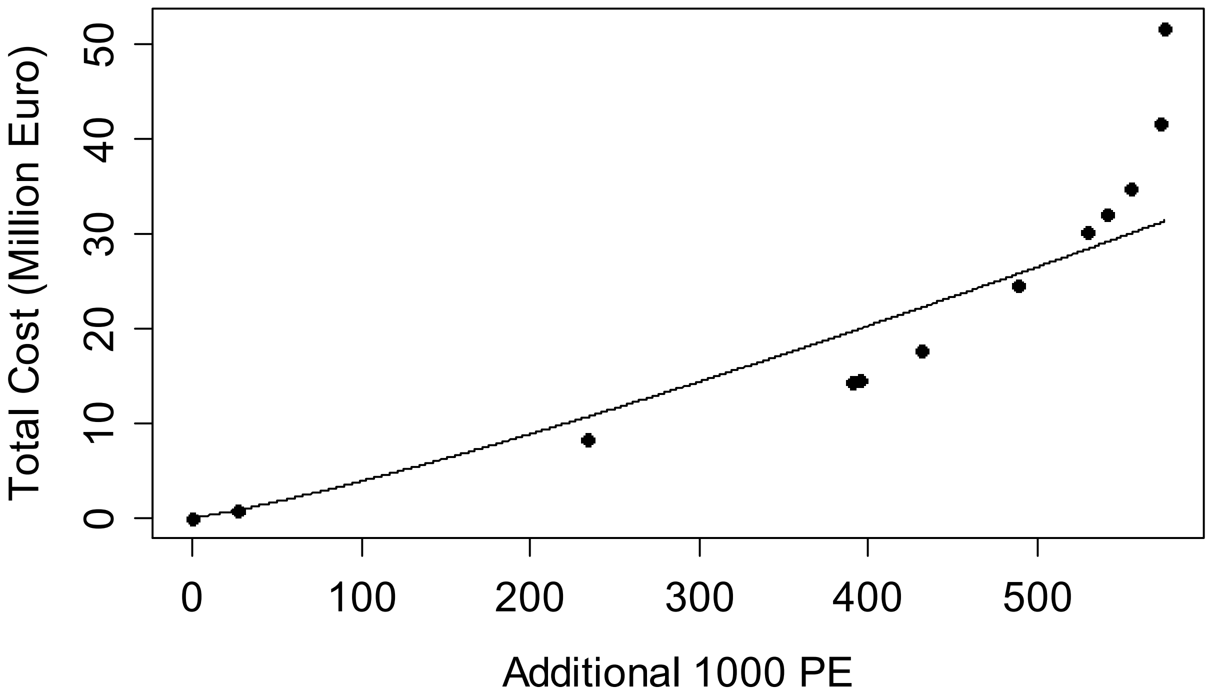
where:

$TC =$ total cost of providing tertiary level WWT (2005 Euros)

$Y =$ additional WWT capacity (PE)

(b) For the 4 drainage basins which comprised only a single watershed, the total cost of improving WWT was simply modelled as the estimated average cost of WWT in the relevant watershed multiplied by the capacity expansion.

Figure 2: Total cost of upgrading to tertiary WWT in the SE-BP drainage basin, estimated as a power law function via OLS regression from sequential expansion of tertiary WWT capacity in the 12 watersheds within the drainage basin.



WWT cost functions produced for the 22 drainage basins by this method are shown in Table 13.

Table 9: Functions describing the total cost (2005 Euros) of improving WWT in the 22 drainage basins as a function of the capacity for improvement (PE)

Drainage Basin	Additional capacity available (weighted PE)	Functional form	Parameters estimated by OLS regression				
			constant	linear parameter	higher order parameter	higher order power	adjusted R^2
DE-BP	104320	power law	0	0.00	7.192	1.2856	1
DE-DS	51275	linear	0	175.65	0	0	(1 ws)
DK-BP	8348	linear	0	18295.20	0	0	(1 ws)
DK-DS	264024	power law	0	0.00	5.710	1.2690	0.9967‡
DK-KT	291496	quadratic	1.96E+06	242.70	2.53E-03	2	0.9995
EE-BP	55097	linear	0	15.84	0	0	(1 ws)
EE-GF	74720	power law	0	0.00	6.607	1.2754	0.9885‡
EE-GR	86468	power law	0	0.00	8.794	1.3219	0.9929‡
FI-BB	88528	power law***	0	0.00	7.942	1.3075	0.9975‡
FI-BS	129823	power law*	0	0.00	5.905	1.2586	0.9991‡
FI-GF	94023	quadratic*	-1.97E+04	16.04	1.18E-03	2	0.9988
LT-BP	2418962	linear	-8.99E+04	23.64	0	0	1
LV-BP	275036	power law	0	0.00	4.113	1.2047	1‡
LV-GR	1488380	quadratic**	1.60E+04	2.90	1.24E-05	2	0.9937
PL-BP	15820718	quadratic	1.29E+06	18.39	5.99E-07	2	0.9981
RU-BP	692560	power law	0	0.00	2.693	1.1462	0.9988‡
RU-GF	4705256	quadratic	1.39E+06	10.10	9.51E-06	2	0.9996
SE-BB	36792	power law****	0	0.00	5.573	1.2521	0.9972‡
SE-BP	575328	power law***	0	0.00	3.907	1.1987	0.9992‡
SE-BS	135258	power law	0	0.00	5.181	1.2438	0.997‡
SE-DS	38748	linear	0	36.77	0	0	(1 ws)
SE-KT	231621	quadratic**	-1.58E+05	33.45	8.81E-04	2	0.9977

* most expensive watersheds in drainage basin excluded
** 2 most expensive watersheds in drainage basin excluded
*** 3 most expensive watersheds in drainage basin excluded
**** 4 most expensive watersheds in drainage basin excluded
‡ For power law functions adjusted R^2 is quoted for the log form regression (Eqn 16)

The total cost functions from Table 13 were applied in the BALTCOST model to estimate the total cost of improving WWT in each of the 22 drainage basins as a function of additional WWT capacity delivered.

2.5.6. Effectiveness of improved WWT treatment in reducing N and P loads discharged to surface water

Following Sozański (2002), quoted in Berbeka et al (fortcoming), we use the following N and P median removal efficiencies for primary, secondary and tertiary level WWT (Table 10).

Table 10. Nitrogen (N) and phosphorus (P) removal efficiencies achieved by different levels of WWT

	Median removal efficiency		
Nutrient	Primary WWTP	Secondary WWTP	Tertiary WWTP
N	15%	55%	80%
P	10%	50%	85%

Since the combined requirements of the Urban Wastewater Treatment Directive (EU UWWTD 1991) and the Water Framework Directive (EU WFD 2000) effectively imply that WWT throughout the EU will ultimately have to be upgraded to tertiary level, in BALTCOST we consider three potential upgrades in WWT (Table 11).

Table 11. Potential upgrades in WWT

Upgrade	From	To	Improvement in N removal	Improvement in P removal
A	No WWT	Tertiary WWT	80%	85%
B	Primary WWT	Tertiary WWT	65%	75%
C	Secondary WWT	Tertiary WWT	25%	35%

Section 3 described how the numbers of individuals connected to particular levels of WWT, and the number of currently un-connected individuals who could feasibly be connected to WWT, were estimated for each drainage basin. These estimates were used to produce a drainage basin-specific estimate of the overall effectiveness of N and P removal delivered by the maximum feasible upgrading of WWT within the drainage basin as follows.

$$\text{Improvement in effectiveness of N removal } = E_N = \frac{N_A(80)+N_B(65)+N_C(25)}{N_A+N_B+N_C} \tag{19}$$

$$\text{Improvement in effectiveness of P removal } = E_P = \frac{N_A(85)+N_B(75)+N_C(35)}{N_A+N_B+N_C} \tag{20}$$

where:

N_A = maximum PE upgradable from no current WWT provision to tertiary WWT
N_B = maximum PE upgradable from primary WWT to tertiary WWT
N_C = maximum PE upgradable from secondary WWT to tertiary WWT
and the resulting improvements in effectiveness are reported as percentages.

The resulting improvements in N and P removal effectiveness per drainage basin are shown in Table 12.

Table 12: Improvements in N and P removal effectiveness per drainage basin

Drainage Basin	Improvement in N removal effectiveness (%)	Improvement in P removal effectiveness (%)
DE_BP	62.4	69.0
DE_DS	58.9	65.8
DK_BP	52.5	60.0
DK_DS	73.2	78.8
DK_KT	71.8	77.5
EE_BP	61.7	68.4
EE_GF	55.9	63.1
EE_GR	52.2	59.7
FI_BB	80.0	85.0
FI_BS	80.0	85.0
FI_GF	80.0	85.0
LT_BP	44.5	52.7
LV_BP	45.6	53.7
LV_GR	42.8	51.1
PL_BP	52.9	60.4
RU_BP	35.3	44.4
RU_GF	33.7	42.9
SE_BB	49.9	57.7
SE_BP	61.5	68.2
SE_BS	56.2	63.4
SE_DS	75.6	81.0
SE_KT	68.4	74.5

Country-specific N and P emission loads per PE were calculated using data reporting country-specific N and P intake through the diet (Hong et al. 2011) in combination with Danish WWT data (Glostrup Kommune 2006) reporting average emission loads for N and P per PE of 4.4 kgN/PE/year and 1.0 kgP/PE/year. Assuming a constant ratio between dietary intake of N and P and N and P emissions per PE across countries produces the N and P emission loads per PE shown in Table 13.

Table 13: N and P emission loads per PE (kg/PE/year) by country

Country	N emission load per PE (kgN/PE/year)	P emission load per PE (kgP/PE/year)
DE	3.88	0.88
DK	4.40	1.00
EE	3.53	0.80
FI	4.19	0.95
LT	4.46	1.00
LV	3.62	0.82
PL	3.98	0.90
RU	3.72	0.84
SE	4.25	0.96

The reduction in N and P emission loads at source (the WWTP) is calculated as:

Annual N Load reduction at source = E_N (Eqn 14) [%] * WWT capacity increase [PE] * N emission load per PE (Table 13) [kgN/PE/year] (21)

Annual P Load reduction at source = E_P (Eqn 15) [%] * WWT capacity increase [PE] * P emission load per PE (Table 13) [kgP/PE/year] (22)

The resulting load reduction in the receiving Baltic Sea region depends on the surface water retentions for N and P for the drainage basin concerned. Population-weighted surface water retentions for N and P were calculated for the WWT measure using the methodology explained in chapter 5, this report. The resulting population-weighted surface water N and P retentions per drainage basin are shown in Table 14.

Table 14. Population-weighted surface water N and P retentions per drainage basin for the WWT measure

Drainage Basin	Surface water N retention (%)	Surface water P retention (%)
DE_BP	18.3	10.8
DE_DS	29.0	14.0
DK_BP	2.0	7.0
DK_DS	13.7	11.1
DK_KT	11.0	9.4
EE_BP	11.0	10.0
EE_GF	6.8	8.0
EE_GR	6.8	11.9
FI_BB	31.7	18.0
FI_BS	37.0	20.4
FI_GF	50.0	25.6
LT_BP	29.5	39.4
LV_BP	16.0	16.8
LV_GR	18.1	29.9
PL_BP	30.5	43.9
RU_BP	46.7	13.6
RU_GF	32.3	44.8
SE_BB	36.1	23.6
SE_BP	47.5	22.1
SE_BS	39.4	21.7
SE_DS	9.0	9.0
SE_KT	45.7	26.2

The reduction in N and P loads reaching the relevant Baltic Sea region from each drainage-basin is therefore given by:

Annual N Load reduction in sea = (E_N (Eqn 14) [%] * WWT capacity increase [PE]

(23)

* N emission load per PE (Table 13) [kgN/PE/year])

* (1 – drainage basin-specific surface water N retention)

Annual P Load reduction in sea = E_P (Eqn 15) [%] * WWT capacity increase [PE]

(24)

* P emission load per PE (Table 13)[kgP/PE/year]

* (1 – drainage basin-specific surface water P retention)

This completes the calculation of the effectiveness of the WWT measure for N and P abatement.

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2.5.7. Data Annex, WWTP

Table 1. Data detailing the total annual costs (*TC*) incurred by wastewater treatment companies in providing (predominantly) tertiary level wastewater treatment in Denmark. P_l denotes labour price (2008 Danish krone/FTE), P_e electricity price (2008 Danish krone/ kWh), *Y* scale of operation (Person equivalent input BOD load– with 1 person equivalent = 21.9 kg BOD annually), S_l share of total costs attributed to labour, S_e share of total costs attributed to operation and maintenance – for which electricity is regarded to be the major input factor. Data obtained through subscription to the DANVA benchmarking database for the Danish wastewater treatment industry http://www.danva.dk/Default.aspx?ID=2794&TokenExist=no

Year	WWT company	*TC*	P_l	P_e	*Y*	S_l	S_e
2008	Ba	21995990	527019	2.37	64932	0.22	0.78
2008	He	93853346	526809	1.95	62831	0.17	0.83
2008	A	448289223	488840	1.36	429611	0.09	0.91
2008	O	246222000	417558	1.14	296027	0.17	0.83
2008	Hj	83353734	557727	1.08	224906	0.3	0.7
2008	Bo	48392062	471998	1.01	109589	0.16	0.84
2008	S	91402609	449315	1	78922	0.13	0.87
2008	F	164765374	417393	0.97	218012	0.04	0.96
2008	G	41838000	473967	0.94	64795	0.16	0.84
2008	E	137688592	398418	0.83	275023	0.15	0.85
2007	Ba	20263163	509960	2.35	70365	0.22	0.78
2007	F	86004283	369168	1.26	172690	0.07	0.93
2007	He	72107489	484168	1.26	54977	0.2	0.8
2007	O	326584000	409931	1.13	276815	0.11	0.89
2007	Bo	46024254	457673	1.06	110653	0.18	0.82
2007	S	93105480	414783	1.01	64367	0.13	0.87
2007	A	381656348	450577	0.95	386420	0.1	0.9
2007	G	33085000	498099	0.94	64795	0.2	0.8
2007	E	87388348	342707	0.86	242466	0.18	0.82
2006	Bo	41129018	460721	3.54	17123	0.21	0.79
2006	S	67989646	405909	3.19	33767	0.12	0.88
2006	He	68772035	457285	2.17	64018	0.21	0.79
2006	G	31299255	463140	2.16	70320	0.18	0.82
2006	Ba	22227272	481755	2.08	66895	0.18	0.82
2006	O	307339000	413455	1.93	257662	0.12	0.88
2006	A	248070965	388945	1.79	340249	0.12	0.88
2006	E	72686361	392001	1.46	290502	0.22	0.78
2006	F	77681703	403367	1.14	189671	0.08	0.92

2. Data detailing current provision of WWT in Baltic littoral countries (from Erik Smedberg, BNI Stockholm)

People connected to any waste water treatment within the Baltic catchment, percentage, year and source.

Country	Percentage;year	Source
Finland	81;2004	Eurostat: Population connected to urban wastewater treatment (ten00021)
Sweden	86;2006	Eurostat: Population connected to urban wastewater treatment (ten00021)
Denmark	89;1998	Eurostat: Population connected to urban wastewater treatment (ten00021)
Poland	62;2007	Eurostat: Population connected to urban wastewater treatment (ten00021)
Germany	95;2007	Eurostat: Population connected to urban wastewater treatment (ten00021)
Lituania	69;2007	Eurostat: Population connected to urban wastewater treatment (ten00021)
Latvia	65;2007	Eurostat: Population connected to urban wastewater treatment (ten00021)
Estonia	74;2007	Eurostat: Population connected to urban wastewater treatment (ten00021)
Norway	78;2007	Eurostat: Population connected to urban wastewater treatment (ten00021)
Russia	64;1999	OECD
Belarus	68;2002	OECD, Ministry of housing and communal services of Belarus
Ukraine	51;2002	OECD, State committee for statistics for Ukraine
Czech republic	75;2007	Eurostat; State of the environment report – Slovak republic
Slovakia	57;2007	Eurostat; State of the environment report – Slovak republic

People connected to primary waste water treatment within the Baltic catchment.

Country	Percentage;year	Source
Finland	0;2001	Eurostat: Population connected to urban wastewater treatment: primary treatment (ten00022)
Sweden	0;2000	Eurostat: Population connected to urban wastewater treatment: primary treatment (ten00022)
Denmark	2;1998	Eurostat: Population connected to urban wastewater treatment: primary treatment (ten00022)
Poland	1;2007	Eurostat: Population connected to urban wastewater treatment: primary treatment (ten00022)
Germany	0;2007	Eurostat: Population connected to urban wastewater treatment: primary treatment (ten00022)
Lituania	8;2007	Eurostat: Population connected to urban wastewater treatment: primary treatment (ten00022)
Latvia	2;2007	Eurostat: Population connected to urban wastewater treatment: primary treatment (ten00022)
Estonia	1;2007	Eurostat: Population connected to urban wastewater treatment: primary treatment (ten00022)
Norway	20;2007	Eurostat: Population connected to urban wastewater treatment: primary treatment (ten00022)
Russia	0	Assumed

Belarus	0	Assumed
Ukraine	0	Assumed
Czech republic	0;2007	Eurostat: Population connected to urban wastewater treatment: primary treatment (ten00022)
Slovakia	0	Assumed

People connected to secondary waste water treatment within the Baltic catchment.

Country	Percentage;year	Source
Finland	0;2001	Eurostat: Population connected to urban wastewater treatment: secondary treatment (ten00023)
Sweden	5;2006	Eurostat: Population connected to urban wastewater treatment: secondary treatment (ten00023)
Denmark	3;1998	Eurostat: Population connected to urban wastewater treatment: secondary treatment (ten00023)
Poland	21;2007	Eurostat: Population connected to urban wastewater treatment: secondary treatment (ten00023)
Germany	2;2007	Eurostat: Population connected to urban wastewater treatment: secondary treatment (ten00023)
Lituania	25;2007	Eurostat: Population connected to urban wastewater treatment: secondary treatment (ten00023)
Latvia	25;2007	Eurostat: Population connected to urban wastewater treatment: secondary treatment (ten00023)
Estonia	13;2007	Eurostat: Population connected to urban wastewater treatment: secondary treatment (ten00023)
Norway	2;2007	Eurostat: Population connected to urban wastewater treatment: secondary treatment (ten00023)
Russia	64	Assumed
Belarus	68	Assumed
Ukraine	51	Assumed
Czech republic	15;2007	Eurostat: Population connected to urban wastewater treatment: secondary treatment (ten00023)
Slovakia	57	Assumed

People connected to tertiary waste water treatment within the Baltic catchment.

Country	Percentage;year	Source
Finland	81;2002	Eurostat: Population connected to urban wastewater treatment: tertiary treatment (ten00024)
Sweden	86;2006	Eurostat: Population connected to urban wastewater treatment: tertiary treatment (ten00024)
Denmark	84;1998	Eurostat: Population connected to urban wastewater treatment: tertiary treatment (ten00024)
Poland	41;2007	Eurostat: Population connected to urban wastewater treatment: tertiary treatment (ten00024)
Germany	93;2007	Eurostat: Population connected to urban wastewater treatment: tertiary treatment (ten00024)
Lituania	36;2007	Eurostat: Population connected to urban wastewater treatment: tertiary treatment (ten00024)
Latvia	38;2007	Eurostat: Population connected to urban wastewater treatment: tertiary treatment (ten00024)
Estonia	61;2007	Eurostat: Population connected to urban wastewater treatment: tertiary treatment (ten00024)
Norway	56;2007	Eurostat: Population connected to urban wastewater treatment: tertiary treatment (ten00024)
Russia	0	Assumed
Belarus	0	Assumed
Ukraine	0	Assumed
Czech republic	60;2007	Eurostat: Population connected to urban wastewater treatment: tertiary treatment (ten00024)
Slovakia	0	Assumed

Annex 2.6. Nox reductions at power plants and ships (not implemented in BALTCOST version 8.0.)

Author: Hasler, B

This measure involves installation of de-NO_X units at large power plants. The maximum capacity of the measure for each country around the Baltic is not set, and therefore the measure is not yet implemented in BALTCOST or the RECOCA model. In the former MARE Cost model (Schou et al 2007) the capacity was arbitrarily set at 1,000 tonnes for each country.

A literature review has been accomplished by Chajkowskij et al (2011, unpublished), leading to the conclusion that the most recent and suitable results are the cost estimates from Illerup et al (2002).

Cost estimates for Nox reductions from power plants are therefore derived from Illerup et al. (2002) where a number of initiatives for reducing NO_X emissions from power plants, as well as cars, are analysed. The estimated costs are shown in Table 1.

Table 1. Estimates of annual total socio-economic costs for different NO_X reducing measures

Technology	Reduction costs, € per tonne NO_X
Offshore wind turbine farms	73
Installation of SCR de-NO_X units at large power plants	
EGR-filter installation in heavy duty vehicles	17
Electrical vehicles	96
	1,688

Source: Illerup et al. (2002), here from Schou et al 2007.

As seen the least reduction costs are found for installation of de-NO_X units at large power plants followed by substituting coal fired power plants by offshore wind turbines and EGR-filter installation in heavy duty vehicles.

Installation of de-NO_X units at large power plants can be chosen as the abatement technology representing the most relevant NO_X – measure as this measure also is the one with the largest emissions reduction potential. Following Schou et al (2007) de-Nox units can reduce the emissions from a power plant producing 350 MW by 3,230 tonnes NO_X per year (Illerup et al., 2002).

NOx reductions at ships: The costs and the capacities estimated for the Baltic NECA are appropriate to use.

Neither Nox reductions at power plants or ships are implemented in RECOCA and BALTCOST as the estimation of capacities for load reductions and the atmospheric loads (deposition) from these sources are currently modelled as a part of Baltic Nest Institute, Denmark. The measures will thus be modelled in BALTCOST during spring 2012.

References:

Neither Nox reductions at power plants or ships are implemented in RECOCA and BALTCOST as the estimation of capacities for load reductions and the atmospheric loads (deposition) from these sources are currently modelled as a part of Baltic Nest Institute, Denmark. The measures will thus be modelled in BALTCOST during spring 2012.

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