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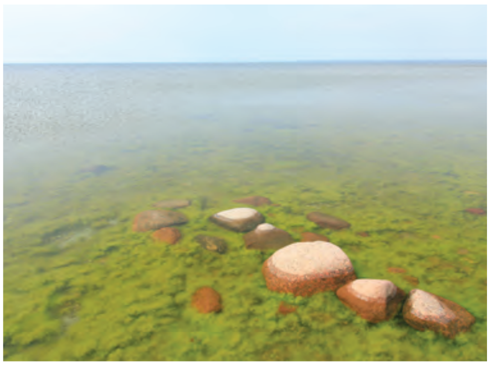
Environmental economic research as a tool in the protection of the Baltic Sea

– costs and benefits of reducing eutrophication



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Kari Hyytiäinen, Kerstin Blyh, Berit Hasler, Lassi Ahlvik, Heini Ahtiainen, Janne Artell and Siv Ericsdotter

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Nordic Council of Ministers
Ved Stranden 18
DK-1061 Copenhagen K
Phone (+45) 3396 0200

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Content

Summary

This report reviews the findings of BalticSTERN, an international research network conducting economic analysis of the on-going and prospective efforts to reduce eutrophication in the Baltic Sea. This report is a companion paper to a summary report: "Worth it: Benefits outweigh costs in reducing eutrophication in the Baltic", which was published as a background paper of the HELCOM Ministerial Meeting in Copenhagen, October 2013.

The network has undertaken surveys to explore the benefits perceived by citizens of Baltic Sea countries from improved water quality and estimated cost-effective combinations of nutrient abatement measures that would fulfill the targets of the HELCOM Baltic Sea Action Plan (BSAP). The cost-benefit analysis reported here evaluated the long-term net economic benefits and ecological consequences of the BSAP. This report evaluates the robustness of these numerical results through model comparisons, sensitivity analyses, and identification of the sources of uncertainty.

The results indicate that the overall benefits of pursuing the proposed nutrient reductions outweigh their aggregate costs, suggesting that the BSAP is an economically sound plan for solving the transboundary eutrophication problem. The cost of inaction, i.e. not implementing the objectives of the BSAP, would be significant. The research tools developed in the BalticSTERN network may aid decision making and inform processes related to the planning, design and evaluation of future international and national water management plans and policies for the Baltic Sea.

1. Introduction

Eutrophication is an enduring and severe environmental problem in the Baltic Sea. The causal relationships driving eutrophication are well known: deteriorating water quality is a consequence of excessively high nutrient pollution from industrial point sources, agricultural land, inadequately treated wastewaters, and atmospheric deposition. To combat eutrophication, the coastal countries of the Baltic Sea have undertaken significant efforts and set forth water policies since the 1970s. Testifying to the efficacy of such policies and measures, recent statistics suggest that nutrient loading peaked some 20 years ago and nutrient loads are now declining (Gustafsson *et al.* 2012, HELCOM 2013). However, the state of the marine environment has not yet improved. The Baltic is still alarmingly eutrophic, despite reduced loading, and these conditions are due to three reasons:

1. There are long time lags between the adoption of abatement measures and measurable improvements in water quality.
2. The Baltic Sea is subject to the impacts of internal loading of phosphorus, which has accumulated in the sea floor sediments during the past decades of excessive nutrient loading, and is released back to the water under anoxic conditions.
3. There are still both unregulated and undetected point sources of nutrients. Thus, patience is needed before the benefits of abatement actions we take today can be observed in the state of the marine ecosystem.

Even though the nutrient loads to the Baltic Sea have been significantly reduced during last two decades, nutrient loads and pollution levels are still too high. Thus, additional nutrient abatement efforts are needed. The Baltic Sea Action Plan (BSAP) (HELCOM 2007) is an international agreement, according to which the riparian Baltic Sea countries and the EU have agreed on the needed nutrient load reductions.[1] The BSAP defines maximum levels of total phosphorus and nitrogen loads to the sea such that the marine ecosystem can recover and a good environmental status can be reached in the future. The load quotas are measured as maximum allowable inputs for each of the riparian countries and to each of the seven sea basins. The BSAP targets were first agreed in 2007, and later revised in the HELCOM Copenhagen Ministerial Meeting in October 2013.

This report is dedicated to elaborating the economic consequences of the BSAP from 2007 (HELCOM 2007): the costs of nutrient abatement and the benefits from expected improvements in water quality. Environmental improvements such as reducing nutrient pollution require public intervention. However, public resources are scarce, and a number of sectors, such as healthcare, education, and defense, compete for them. This scarcity gives the impetus for economic analyses that guide decision makers on the societal impacts of planned public projects across different sectors. An economic analysis of on-going and future efforts to reduce eutrophication in the Baltic might include evaluation of

- how to improve the state of the sea in a cost-effective manner, that is, in a way that the target is reached at the lowest cost for society.
- how large the societal benefits of improved water quality and increased provision of ecosystem services will be.

The objective of this report is to review the main findings of BalticSTERN, an international research network conducting cost-benefit analysis on the environmental problems of the Baltic Sea with a focus on eutrophication. It is a companion paper to the BalticSTERN summary report: "Worth it: Benefits outweigh costs in reducing eutrophication in the Baltic", which was published as a background document of the HELCOM 2013 Ministerial Meeting. This report discusses the aggregated costs and benefits of nutrient abatement, cost-effective nutrient abatement, different uses of the sea, as well as people's attitudes and values regarding improvement of the marine environment. Compared to other BalticSTERN reports, this paper has been designed to give a broader perspective on how the results obtained may inform and serve societal

[1] One of the main foci of the BSAP is combatting eutrophication, but it also sets targets to reduce the loads of hazardous substances, to improve biodiversity, and to regulate maritime activities. In this report, we only focus on eutrophication.

decision making. The report also discusses some of the most salient uncertainties pertaining to the results.

This report is structured as follows. The second chapter explains the project to be evaluated: the Baltic Sea Action Plan. The third chapter reports recent research results on the costs of implementing the BSAP. The fourth chapter elaborates results on the uses of the marine environment in the riparian Baltic Sea countries, and presents the research results on the benefits of improvements in water quality. The fifth chapter provides the results of the cost-benefit analysis. The sixth chapter explains how the data and models can be used as decision aids and the final seventh chapter provides conclusions. At the beginning of chapters 3–5 there is a short summary of the main outcomes of each chapter.

2. Current loads and targets of the Baltic Sea Action Plan

This report is dedicated to evaluating the economic impacts of implementing nutrient reduction plans as articulated in the Baltic Sea Action Plan (2007). In order to evaluate any environmental project or policy, we need information on

- the current level of pollution.
- the target level of pollution (or maximum allowable inputs).

The difference between these two represents the needed reduction.

The economic impacts of implementing the BSAP have been examined in several papers. The first studies estimated the total costs of implementing the BSAP based on the reference loads and target loads as specified in the agreement (see Gren 2008a,b, Elofsson 2010a,b, Hasler *et al.* 2012). However, as time passes and the level of pollution changes due to the implementation of some of the agreed water protection efforts, the subsequent analysis may use the revised load statistics as the present state of pollution. This is the case with the BalticSTERN calculations, where the assumption of the initial level of nutrient pollution is based on the most recent flow-normalized PLC-5 load statistics (2004–2008) available in 2011,[2] when the analysis was conducted. It is important to note that if the assumptions regarding the initial or target loads vary, the results of cost studies will not be directly comparable. In the following we explain and specify these two alternative settings (Alternatives 1 and 2) more in detail. These two alternatives will be referred to throughout this report.

[2] Flow normalization is a process to smooth out natural stochasticity in waterborne nutrient loads due to variations in hydrology. The process makes it easier to compare loads during dry and wet years with each other.

Alternative 1: The reference load and target of the original BSAP (HELCOM 2007)

In 2007, the countries around the Baltic signed the Baltic Sea Action Plan (BSAP), which was planned to replace the earlier target of a uniform 50% nutrient load reduction with more subtle sea basin-specific nutrient load reduction targets (HELCOM 2007). The BSAP aims at restoring the good environmental status of the sea by 2021 in a way that is "fair and acceptable to all HELCOM contracting parties" (HELCOM 2007).

In the BSAP, the environmental status of the sea has been measured since 2007 in terms of water transparency indicated by the annual Secchi depth. The required nutrient loads were calculated from the transparency target in two phases. In the first phase, the total loads to each sea basin were reduced so that the water transparency targets were reached. In the second phase, the allocation of the total nutrient reduction to each basin was divided between the nine littoral countries. In the calculation of the load reduction targets, it was assumed that countries would have implemented the EU Urban Wastewater Treatment Directive (UWWT), and the remaining load reduction was then divided among the bordering countries based on their current share of the total load.

Table 1. Initial riverine loads (1997–2003) and targets of the BSAP

1A. Loads by sea basin	Reference level (1997–2003)		Target	
	N, tonnes	P, tonnes	N, tonnes	P, tonnes
Kattegat	64,260	1,570	44,260	1,570
Danish Straits	45,890	1,410	30,890	1,410
Baltic Proper	327,260	19,250	233,250	6,750
Bothnian Sea	56,790	2,460	56,790	2,460
Bothnian Bay	51,440	2,580	51,440	2,580
Gulf of Riga	78,400	2,180	78,400	1,430
Gulf of Finland	112,680	6,860	106,680	4,860
Total	*736,720*	*36,310*	*601,710*	*21,060*

1B. Load reduction by country	Needed load reduction	
	N, tonnes	P, tonnes
Denmark	17,210	16
Estonia	900	220
Finland	1,200	150
Germany	5,620	240
Latvia	2,560	300
Lithuania	11,750	880
Poland	62,400	8,760
Russia	6,970	2,500
Sweden	20,780	290

These reference loads and the targets by sea basin were used by Gren (2008a,b), Elofsson (2010a,b) and Hasler *et al.* (2012).

Alternative 2: Updated loads (years 2004–2008) and original BSAP targets (HELCOM 2007)

The economic analyses conducted in the BalticSTERN were based on flow-normalized statistics from HELCOM's PLC (HELCOM 2011) for the period from 2004–2008, which was the most recent available data set when the analyses were conducted. Normalizing the annual loads with respect to annual riverine flows is a technique used to remove the impacts of annually varying weather conditions on nutrient loading. Note that the reference loads in 1997–2003 (see Table 1A) and the flow-normalized loads from 2004–2008 (see Table 2A) are not directly comparable. The total loads from the latter period are smaller, suggesting that some advancement had been achieved in nutrient abatement during that period. However, part of the difference may also be explained by differences in the types of averaging used and the quality of data between these two periods of time.

Table 2. Updated loads (years 2004–2008) and targets of the BSAP

2A. Loads by sea basin	Loads (2004–2008)		Targets	
	N, tonnes	P, tonnes	N, tonnes	P, tonnes
Kattegat	57,251	1,562	44,260	1,570
Danish Straits	42,307	1,385	30,890	1,410
Baltic Proper	294,893	16,000	233,250	6,750
Bothnian Sea	55,396	2,186	56,790	2,460
Bothnian Bay	53,843	2,335	51,440	2,580
Gulf of Riga	86,141	2,985	78,400	1,430
Gulf of Finland	116,871	6,267	106,680	4,860
Total	*706,702*	*32,720*	*601,710*	*21,060*

2B. Load reduction by country	Remaining load reduction	
	N, tonnes	P, tonnes
Denmark	8,607	0
Estonia	1,490	201
Finland	1,768	224
Germany	4,856	0
Latvia	1,782	1,681
Lithuania	13,263	1,656
Poland	40,638	6,828
Russia	5,326	1,354
Sweden	16,656	180

The present loads estimated from the period of 2004–2008 (Alternative 2) are 4% lower for nitrogen and 10% lower for phosphorus than the reference loads for 1997–2003 (Alternative 1). The nitrogen loads have been reduced particularly to the Kattegat (-11%), Baltic Proper (-10%), and Danish Straits (-8%), but increased to the Gulf of Riga (+10%). The phosphorus loads have been reduced to the Baltic Proper (-17%), Bothnian Sea (-11%), Bothnian Bay (-9%), and Gulf of Finland (-9%), but increased to the Gulf of Riga (+37%).

3. Cost-effective reductions of nutrients to the Baltic Sea

Main messages

The costs of achieving the nutrient load reduction to the Baltic Sea required by the BSAP2007 have been estimated using two Baltic-wide cost-minimization models: BALTCOST and the MTT cost model. The total cost of reducing nutrient loads from the level observed in 1997–2003 to meet the targets of the BSAP is estimated to be EUR 4.6 billion/yr. This result is well in line with the earlier cost estimates of EUR 4.2–4.5 billion/yr. The load reduction in the period 2004–2008 reduced the necessary load reductions, and the costs of meeting these BSAP target levels are significantly lower, between EUR 1.4 and 2.8 billion/yr. Sensitivity analysis indicates that the use of assumptions on retention from previous studies might underestimate the costs compared to the more realistic modeling of retention in the BalticSTERN models. The sensitivity analysis also indicates that simplifying the assumptions of baseline agricultural production might overestimate the costs, and detailed spatial information is therefore recommended.

3.1 Introduction

As mentioned in chapter 2, HELCOM's Baltic Sea Action Plan from 2007 sets maximum allowable inputs of nutrients to each sea basin of the Baltic Sea (HELCOM 2007, HELCOM 2013). Huge efforts with potentially significant economic costs are required to fulfill the required nutrient load reductions, and careful minimization of the costs is therefore socially desirable. One of the objectives of this report is to transfer knowledge from researchers to decision makers on cost-effective nutrient abatement solutions for the Baltic Sea, and the aim of this chapter is to present, analyze, and discuss recent cost-effectiveness analyses and results, with special emphasis on the analyses performed by the BalticSTERN network in 2010–2013.

The aim of the cost studies and model assessments of the Baltic is to:

- identify least cost solutions and the minimum total costs in achieving the BSAP targets.

- ascertain the extent to which measures should be implemented and where.

The use of existing model results on the most cost-effective abatement of eutrophication in the Baltic Sea can inform stakeholders and thereby increase the understanding of how nutrient reductions can be achieved most cost-efficiently among Baltic Sea countries, including the Nordic countries: Finland, Sweden, and Denmark. By comparing the existing research results and the assumptions behind the model calculations, the aim is to:

- shed light on how load reductions can be achieved with a cost-efficient distribution between countries and measures.
- explain the drivers of the results, the uncertainty, and the importance of this when interpreting the results.

The abatement measures include agricultural measures, the treatment of wastewater from industry and households, and measures focused on transport and other airborne sources. Because these results are new, the discussion is also considered useful for future research in terms of improving knowledge on what information stakeholders find useful.

The results of this analysis are based on the assumption that the abatement measures can be implemented without any transaction costs related to the use of economic instruments or distributing money between the economic agents. This means that analysis of the incentives to implement abatement measures, as well as distributional effects, is excluded from this study. This does not mean that the BalticSTERN researchers interpret these problems as unimportant, as the opposite holds. These challenges are crucial, but an overall view of the total costs, the minimum cost solutions, and the resultant distribution of these between countries and measures provides a necessary background for further assessments of implementation and distributional issues. Furthermore, measurement of the total costs is essential for cost-benefit assessment.

3.2 Methodology: The models and the measurement of costs and effects

The costs of achieving the load targets defined in the BSAP were estimated using two models, one developed in Finland as part of the PROBAPS project (Ahlvik *et al.* 2014, BalticSTERN 2013), and the other in Denmark as part of the work of the Baltic Nest Institute and the BONUS project RECO-

CA (Hasler *et al.* 2012, Wulff *et al.* 2014, BalticSTERN 2013b). The use of two models with different assumptions and modeling frameworks is useful to provide insights into the level of certainty and uncertainty relating to the cost estimates. Both models are run for equal assumptions with respect to the nutrient load reduction targets and loads, and the results from modelling these assumptions have not been fully published before.[3] Both models were developed for the seven sea regions and nine littoral countries around the Baltic (Figure 1). Nutrient loads can be reduced by implementing abatement measures from the most important sources of pollution, such as agriculture and wastewater treatment.

Figure 1. The Baltic Sea divided into 7 sea basins and its catchment area divided into 23 sub-catchment areas. Sea basins: A. Bothnian Bay, B. Bothnian Sea, C. Baltic Proper, D. Gulf of Finland, E. Gulf of Riga, F. Danish Straits, G. Kattegat

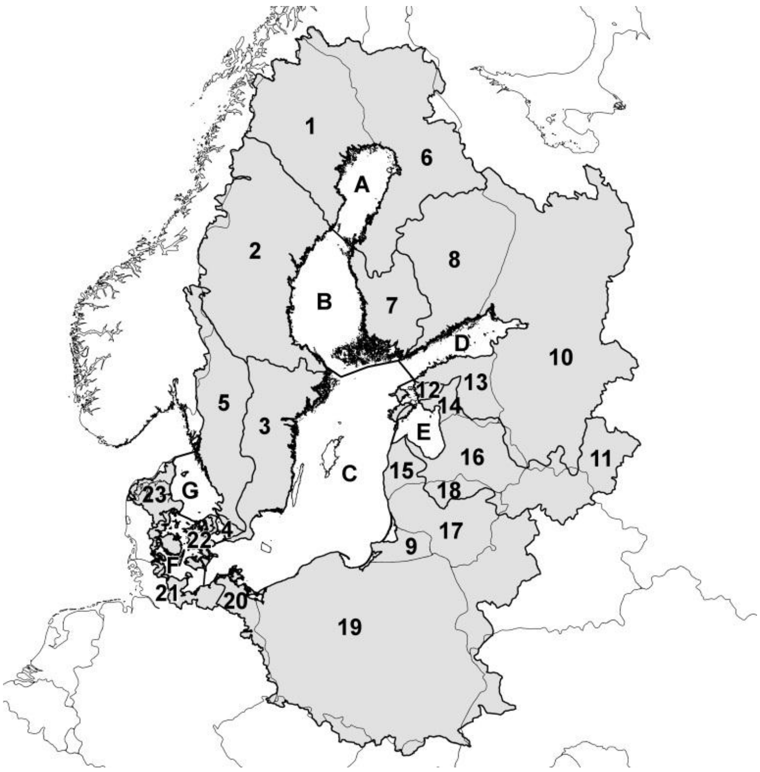

Illustration based on Larsen 2008; Source: Hyytiäinen *et al.* 2013.

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[3] The assumptions have been used for previuos modelling with the MTT Cost model (Ahlvik *et al.* 2014) but these assumptions have not been used in previous analyses using BALTCOST.

The modeling conducted with both of the models is based on detailed data on the following:

- Land use in the Baltic Sea catchments.
- The baseline application of nutrients.
- The modeled retention of nitrogen and phosphorus in soil and freshwater within the catchments.
- The existing wastewater treatment capacity
- The potential for implementing agricultural measures and restoring wetlands.
- The costs and effects of implementing these measures.

These detailed datasets, including measurement of maximum implementation capacities for the various abatement measures and extensive data on nutrient retention in each drainage basin, have been established through intensive cooperation between economists and natural scientists (cf. Wulff *et al.* 2014), and because of this cooperation, the data underlying the modeling is much more detailed than in previous studies. Consistency is ensured by estimating the costs using the same year for the estimated costs of all measures (2005 for BALTCOST, 2007 for the MTT cost model).

3.2.1 The MTT cost model (Ahlvik et al. 2014)

MTT's cost model is a coupled economic-ecological model framework that allows estimation of the costs and effects of abatement measures, as well as solving of the cost-effective set of measures. The base year of the model is 2008. The model divides the catchment of the Baltic Sea into 23 sub-catchments, and the sea into seven sea regions such that each combination of a country and a sea basin forms a single unit. The estimated costs and effects of abatement measures in each of these catchments are based on country- and sub-catchment-specific data. A non-linear optimization problem is then solved to find the cost-minimizing solution such that the given constraints and the maximum allowable loads to each sea basin are satisfied. The problem is solved using the KNITRO solver and optimization toolbox in Matlab.[4]

[4] KNITRO is a solver for nonlinear optimization developed by Ziena Optimization LLC. The KNITRO optimization algorithm can be used with MATLAB optimization toolbox.

The model contains the following nutrient abatement measures:

- Reduction of fertilizer application.
- Introduction of catch crops.
- Reduction of the number of pigs, poultry, and cattle.
- Restoration of wetlands.
- Construction of sedimentation ponds.
- Improvement of wastewater treatment.
- Reduction of the use of phosphates in detergents.

The model aims to carefully specify the interactions between abatement measures. For example, improving wastewater treatment reduces the effectiveness of banning phosphate in detergents in the same catchment. This, in turn, increases the marginal cost of banning detergents. These interactions can sometimes distinguish two strategies: the reduction of leakage from the source, or capture of the leached nutrients. The banning of phosphate-containing detergents represents the former, whereas improvement of wastewater treatment represents the latter strategy.

Another emphasis of the MTT model is to take into account the dynamics of the soil phosphorus stock. Phosphorus from fertilization accumulates in agricultural soils, and this stock slowly discharges to inland waters. This causes long time lags in phosphorus-related measures, and the full effect of phosphorus fertilization reduction is only seen after decades. The efficiency of related measures, such as catch crops, wetlands, and phosphorus ponds, is affected by the lags in the leaching of phosphorus from agricultural soils.

3.2.2 The BALTCOST model (Hasler et al. 2012)

BALTCOST is a static cost minimization model that minimizes the costs of achieving the nutrient load reduction targets for the Baltic Sea. The model can therefore be used as a consistent scenario tool to estimate the total minimum costs of achieving different targets. The model also identifies the minimum-cost combination of nitrogen (N) and phosphorus (P) abatement measures across the catchments that drain into a particular sea sub-basin, subject to satisfying the reduction targets for *both* N and P loads into that particular sea sub-basin.

The development of the BALTCOST model has focused on consistent estimation of the costs of the measures to achieve nutrient load reductions both in time and across different regions, as well as improvements in catchment modeling by intensive cooperation with natural scientists, providing improvements in the estimates of the associated impact of the abatement measures on coastal nutrient loads, as well as improved assessment of the capacity for implementing the different measures in different parts of the catchments. The costs from implementing measures as changes from the baseline situation (2005) are modeled using detailed databases of human activities in the catchments, as well as estimates of nutrient reductions related to these, using models such as the DAISY model (Andersen et at 2011) and the MESAW retention model (Stålnacke *et al.* 2011).

The BALTCOST model can be used to estimate the total abatement costs as well as the marginal costs of abatement, both of which are essential for policy advice. The abatement measures included in the BALTCOST model are:

- reductions in fertilizer application to arable crops
- catch crops in spring-sown cereals
- reductions in livestock numbers, both pigs and cattle (where poultry are included in pig production through weighting of the livestock production at 10x10 km resolution)
- restoration of wetlands on agricultural land
- improvement of wastewater treatment.

Implementation of costs and load reduction effects from measures like constructed wetlands, reductions of NOx emissions from power plants and ships as well as from improved utilisation of the nutrients in livestock manure are the aim of future development of the BALTCOST model. The utilisation of livestock manure is especially important in those countries in those countries where the utilisation rate is currently low (50% of the nutrient content utilized or lower) NO_x reductions from power plants and ships, as well as measures for the increased utilization of livestock manure to reduce nutrient loads from livestock farms in those countries where the utilization rate is currently low (50% of the nutrient content utilized or lower). The measures for reductions of atmospheric emissions are more relevant now than before, because the deposition of nitrogen from these sources is now included in the load compilation and in the basis for the assessment of the targets (The Copenhagen Ministerial Declaration, HELCOM 2013).

The BALTCOST model uses separate load reduction targets for nitrogen and phosphorus for the seven Baltic Sea sub-basins (see Figure 1). Consequently, the cost minimization is solved separately for each subbasin, such that the BSAP targets are reached, to produce a cost-efficient solution for the Baltic as a whole. In the versions used for the present modeling, neither the MTT cost model nor BALTCOST account for nutrient transport between sea sub-basins or sources and sinks of nutrients internal to the sub-basins themselves, as these were already considered in the estimation of the BSAP targets for nutrients.

Cost functions, effect functions, capacity constraints (that measure the maximum extent to which abatement measures can be implemented), and catchment-scale nutrient retentions are calibrated using relevant combinations of data at national, watershed and 10x10 km resolution scale, thereby using the disaggregated data from the other components of the RECOCA project (cf. Wulff *et al.* 2014).

The BALTCOST model optimizes the implementation of the six abatement measures in each of the drainage basins to reach the targets specified for all the sea sub-basins, using the solver CONOPT within the software GAMS.[5] The model approach utilizes retention coefficients and capacity constraints, as well as cost and effect functions that are drainage basin-specific for the 22 drainage basins (catchments). In other words, retention coefficients and capacity constraints were calibrated to each drainage basin using relevant combinations of data at national, watershed, and 10x10 km resolution. The six measures and their effects are assumed to be independent so that the effect of one measure will not be influenced by the implementation of another measure. This assumption in BALTCOST might overestimate the load reduction effect of the measures, and hence underestimate the costs. Further research is needed to estimate the effect of implementing the measures together, for instance the effects on nutrient reductions from wetlands when nutrient transport through wetlands decreases, and the effect of catch crops when fertilizer application is reduced at the same time. These effects are not presently known. The modeled capacity of the abatement measures, i.e. the maximum extent to which the measures can be implemented in each catchment, is carefully estimated for each of the measures. The measurement and considerations are described in detail in Hasler *et al.* (2012).

[5] CONOPT is a solver for large-scale nonlinear optimization (NLP) developed and maintained by ARKI Consulting & Development A/S. The CONOPT solver is part of the GAMS modeling software.

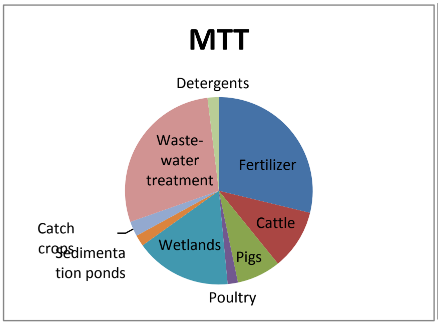
3.3 The BalticSTERN results

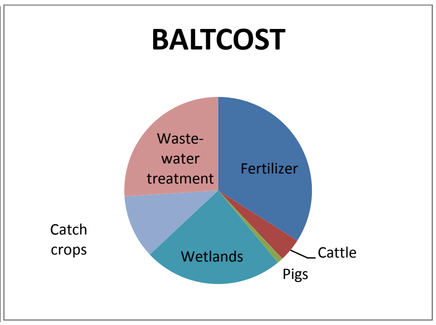
3.3.1 Cost of meeting the BSAP targets

The total cost of achieving the maximum allowable loads to each basin defined in BSAP from the 2004–2008 load level (Tables 2a and 2b, which were used for the BalticSTERN cost-benefit analysis) was estimated to lie between EUR 1,400 and 2,300 million annually. The interval is explained by differences in the models' cost-functions, assumptions concerning the effectiveness of measures, and initial data, for instance on crop distribution and capacities. The differences between the models are carefully described and discussed in BalticSTERN (2013), and the sensitivity of some of the model assumptions is explored in chapter 3.4. The effect of country-specific reduction targets was analyzed using the MTT cost model, and the model results for country-wise implementation indicate that the annual cost will increase from EUR 2,300 million to EUR 2,800 million per year. The efficiency loss of the country-specific targets, compared to the cost-effective allocation of measures between countries, is around EUR 500 million annually.

The cost-effective combination of measures includes, for both models, the improvement of wastewater treatment in the Baltic States (Estonia, Latvia and Lithuania) and Poland, and reduction of phosphorus fertilization, particularly in areas with high soil phosphorus levels, that is, parts of Finland, Germany, and Denmark. Other low-cost measures include the construction of sedimentation ponds and banning of phosphorus in laundry detergents. The reduction of livestock production is the most expensive measure according to both models. The cost-effective distribution of measures can be seen from Figure 2. Wetlands, fertilizers and catch crops take up a greater share of the nutrient reduction in the BALTCOST model solution than in the MTT cost model, because there are fewer measures for the reduction of phosphorus loads in BALTCOST and more expensive measures have to be used. On the other hand, the MTT cost model has a smaller number of measures to reduce nitrogen loading than the BALTCOST model. Therefore, expensive measures, such as reducing the numbers of cattle, pigs, and poultry, had to be used in the Danish Straits and Kattegat catchments to reach the nitrogen target.

Figure 2. Comparison of the cost-effective distribution of measures modelled by the MTT cost model and the BALTCOST





To explore the effects of increasing load reduction targets, the BALTCOST model was used to estimate the cost of different abatement levels for each sea basin. Figure 3a shows the costs and the abatement measures for increasing the obtainment of the original BSAP 2007 target level in the Baltic Proper.[6] Figure 3b similarly illustrates the cost of nitrogen reduction in the Danish Straits, up to the maximum load reduction capacity in the model. These two sea basins are used to illustrate the effect of increased load reduction targets, as the P load reduction target is binding for the Baltic Proper, and the N load reduction target is binding for the Danish Straits. Shifting the load reduction targets downwards will therefore influence the minimum cost solution to a very significant degree, as can be seen from the drastic increase in costs from 60% BSAP 2007 implementation to 74% implementation of the phosphorus target in the Baltic Proper, which is the highest achievable reduction with the available six measures in BALTCOST. A similar figure is apparent for the Danish Straits, where the cost increases dramatically between 70% and 86% fulfillment of the original BSAP 2007 load reduction targets.

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[6] Figures 3a and b show increasing implementation of the original BSAP 2007 targets: from 0% up to 74% of these BSAP targets for phosphorus load reductions to the Baltic Proper (Figure 3a), and from 0% to 87.5% of the nitrogen load reduction targets to the Danish Straits (Figure 3b). In both of these sea basins, the full BSAP targets cannot be met, and 74% and 87.5% are the maximum possible reductions with the current composition of measures and capacities. For these estimations, the total costs are estimated, and the loads and reduction targets mentioned in Alternative 1 in Chapter 2 have been used (cf. Table1).

Figure 3a. The costs of reducing phosphorus loads to the Baltic Proper: increasing fulfillment of the original BSAP 2007 targets (Alternative 1)

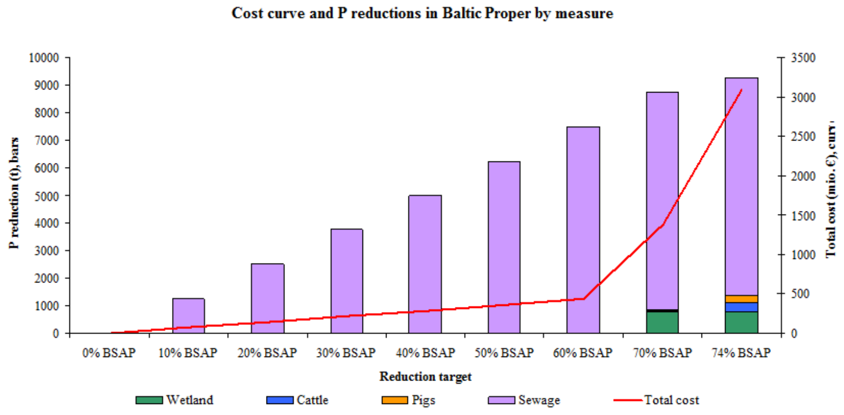
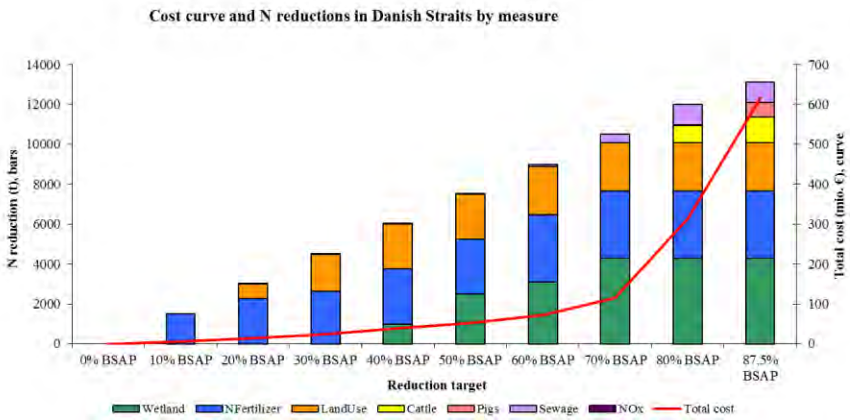


Figure 3b. The costs of reducing nitrogen loads to the Danish Straits: increasing fulfillment of the original BSAP 2007 targets (Alternative 1)



As can be seen from Figure 3a, improved wastewater treatment is the most important measure to reduce phosphorus loading to the Baltic Proper, followed by wetland restoration and livestock reductions. This solution is severely restricted by the limited number of measures, and introduction of additional measures will therefore reduce the costs.[7]

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[7] The reason for the limited number of measures is that the BALTCOST modeling is based on the consistent use of data and model results from catchment models, and measures with an uncertain effect on nutrient load reductions were not included. The number of measures is specifically restricted for phosphorus, and greater knowledge of phosphorus measures is therefore important.

Figure 3a only illustrates phosphorus, as the phosphorus targets are the "driver" for the results in this sea basin, and the nitrogen reduction targets in the sea basin are fulfilled when the phosphorus targets are met. In the Danish Straits the situation is the reverse, and the nitrogen targets are the drivers for the solution. From Figure 3b we can see that the set of abatement measures is more diverse, mainly consisting of agricultural abatement measures. Fertilizer reduction is favored when the nutrient reduction targets are low, while wetland restoration and catch crops ("land use") also play a major role for high reduction targets.

Table 3. Cost allocation between countries (EUR million /year)

Model	BALTCOST (Alternative 1: 1997–2003 as the base year)	MTT (Alternative 2: 2004–2008 as the base year)	MTT (Alternative 2: 2004–2008 as the base year)	BALTCOST (Alternative 2: 2004–2008 as the base year)
Target	**Basin**	**Basin+country**	**Basin**	**Basin**
Denmark	371	620	630	122
Estonia	32	36	78	74
Finland	17	49	23	16
Germany	472	651	480	113
Latvia	227	123	85	141
Lithuania	406	134	101	231
Poland	2,385	752	544	373
Russia	507	113	105	277
Sweden	272	326	290	84
Total	*4,689*[*]	*2,803*	*2,336*	*1,430*

*As mentioned in Figure 3a,b, the targets of the original BSAP2007 could not be met in the Baltic Proper and Danish Straits because of the limited number of measures. The costs should therefore be considered as an underestimation. On the other hand, we assume that the addition of more relevant measures to reduce loads from agriculture will reduce the costs.

Table 3 summarizes total costs of meeting the BSAP targets for different initial loads (Alternatives 1 and 2 in Tables 1 and 2), models (MTT and BALTCOST), and targets (basin and country targets). The two different sets of model results from the MTT model are from running the model for sea region-specific load reduction targets and for country-specific load reduction targets. The costs of meeting the basin load targets according to the BALTCOST model when run with the BSAP targets from 2007 (Hasler *et al.* 2012) are significantly higher compared to the costs estimated by Ahlvik *et al.* (2014), and the costs are even further reduced when running the BALTCOST model with the same assumptions as the MTT cost model (Alternative 2). The model results using 1997–2003 and 2003–2008 as different baselines for the initial loads and targets are not directly comparable, because of these differences in assumptions.

The significant changes in total costs for these different load reduction targets when using BALTCOST can be explained by the following:

- The increasing costs when the model has to use livestock reduction measures (cf. Figure 3). The costs therefore increase to a very high level when modeling the targets within Alternative 1, because all available abatement measures, even the ones with very high marginal costs such as the reduction of livestock, have to be used to fulfill the phosphorus reduction targets in the Baltic Proper and the nitrogen reduction targets in the Danish Straits.
- The load reduction targets are allocated differently between sea regions in the two alternatives, i.e. lower load reduction targets for phosphorus in the Baltic Proper and for nitrogen in the Danish Straits and Kattegat. This means that when the targets from Alternative 2 are used in both the MTT cost model and BALTCOST, there is less need for drastic high-cost measures. The dramatic increases in costs, modeled by BALTCOST, are illustrated for both the Baltic Proper and the Danish Straits in Figures 3a and 3b.

The country-specific load reduction targets, as defined in the BSAP, are based on the "polluter pays principle". Following this principle neglects spatial variability in the availability, unit costs, and effectiveness of nutrient abatement measures across regions and countries. The two different model results from the MTT model indicate that the current country-specific reduction targets are not cost-effective and the total cost can be reduced by EUR 500 million annually if measures are implemented in countries where their marginal cost are the lowest.

3.4 Comparison with other studies, sensitivity analysis and uncertainty

To analyze the robustness of our results, we compare them here with other cost-effectiveness studies (see Table 4), and perform a set of additional sensitivity analysis computations to check how changes in some of the fundamental assumptions and parameter values affect the results.

3.4.1 *Comparison with previous studies*

A number of previous studies have addressed the problem of cost-effective nutrient reduction to the Baltic Sea (Gren *et al.* 1997; Turner *et al.* 1999, Gren 2001, Gren and Folmer 2003, Schou *et al.* 2006, NEFCO 2007, Gren 2008a,b, Elofsson 2010a,b). Fewer studies have specifically addressed the costs of implementing the BSAP (Gren 2008a,b, Elofsson 2010a,b).

Gren (2008 a,b), Elofsson (2010a,b) and Hasler *et al.* (2012) used static models to determine the cost-effective combination of nutrient abatement measures. The models of Elofsson (2010a,b) and Hasler *et al.* (2012) were set up to meet the maximum allowable loads defined in BSAP using the nutrient loads from 1997–2003 as a base statistics (Alternative 1, see Table 1). Gren (2008a,b) used the same reference period, but only considered the country-specific allocation of loads. The overall costs of all these three studies are of the same order of magnitude as the results of BALTCOST for the same target. As earlier mentioned (chapter 2), the BalticSTERN study used the most recent load estimates from 2004–2008 as base statistics (Alternative 2, see Table 2). The required reductions to reach the maximum allowable loads were smaller, and hence the total cost of reaching these targets was significantly lower than in Gren (2008a,b), Elofsson (2010a,b), and Hasler *et al.* (2012).

Table 4. Comparison of estimated total costs between studies

Aggregate load reduction target	Ahlvik *et al.* 2014 (MTT model)	BALTCOST results for present study	BALTCOST results for present study	Gren 2008 (a,b)	Elofsson 2010 (a,b)
Nitrogen (tonnes/ year)	102,624	135,000	102,624	135,000	135,000
Phosphorus (tonnes/ year)	10,555	15,250	10,555	15,250	15,250
Initial loads	**2004–2008 (HELCOM PLC-5)**	**1997–2003 (HELCOM 2007)**	**2004–2008 (HELCOM PLC-5)**	**1997–2003 (HELCOM 2007)**	**1997–2003 (HELCOM 2007)**
		Costs, EUR million/yr			
Denmark	629	472	84	96	451
Estonia	78	32	74	132	25
Finland	23	17	16	79	7
Germany	480	371	113	42	39
Latvia	85	227	231	172	96
Lithuania	101	406	141	377	161
Poland	544	2,386	373	3,313	2,204
Russia	105	507	277	205	962
Sweden	290	272	84	84	585
All	2,336	4,689	1,430	4,251	4,533

3.4.2 *Sensitivity analysis on the impact of baseline crop distribution on the effect of measures*

All models are based on assumptions that simplify reality, and it is therefore important to address the caveats and uncertainty of the results. Sensitivity analysis can be used to explore the importance of such assumptions. Next, we examine the consequences of changes in some of the fundamental assumptions for the results by using the static BALTCOST model, which is more flexible and better suited for such analysis than the dynamic MTT model.

As mentioned, one of the measures applied in both the MTT model and in BALTCOST is N fertilizer reduction. Total fertilization consists of inorganic fertilizers and animal manure, which is assumed to be fully and evenly spread on fields. Reducing the use of inorganic fertilization or manure reduces nutrient leaching from the fields, but has a cost in the form of decreased crop yields. The fundamental equations in the cost calculations for fertilizer reductions are therefore the crop- and drainage basin-specific yield functions describing the dose-response relationship between nitrogen fertilizer application and the crop yield. The yield functions are increasing, but concave, functions of the applied amount of fertilizers, indicating that as more fertilizers are used, the smaller the increase in yield will be. In the BALTCOST model, it is assumed that the initial level of fertilization is the economically optimal level in terms of the constructed profit function. Any reduction below this point is associated with a cost, and this cost will increase exponentially in reductions. The MTT cost model uses data on the sales of inorganic fertilizers as the initial fertilization levels.

In the MTT cost model (Ahlvik *et al.* 2014), the costs of fertilizer reductions in the catchments are estimated by assuming that spring barley is the representative crop, and hence the effect on yields, costs, and nutrient leaching reductions are described as if all agricultural crops react in the same way as barley. In BALTCOST (Hasler *et al.* 2012), the cost of fertilizer reduction is for a total of 14 crops grown in 117 sub-catchments, which are aggregated up to the level of the 22 drainage basins.[8]

Since the assumptions of land use differ between the models, the BALTCOST model can be run for the same assumptions as the MTT model, and by doing this the effects on the costs and the choice of fertilizer reductions as a measure can be modeled and measured for both assumptions:

- Assuming barley as a representative crop.
- Assuming a realistic crop distribution.

When the assumption is spring barley as a representative crop, the cost of fulfilling the BSAP targets as anticipated in the BalticSTERN assessments is estimated to be EUR 1,798 million/yr, while the cost is lower when anticipating a realistic land use: EUR 1,431 million/yr. The difference can be explained by the fact that the effect on nutrient load reductions from spring barley is lower compared to other crops. This sensitivity analysis indicates that the assumption of spring barley as the representative crop might overestimate the costs in the MTT model results, and that the total costs – when looking at this assumption with all else equal – of achieving the BSAP targets might therefore be lower than estimated by the MTT model.

3.4.3 Sensitivity analysis of the retention parameters

The BALTCOST and MTT cost models use the MESAW-modeled retentions, documented in Stålnacke *et al.* (2011). These retentions are modeled for soil, groundwater, and surface water on a detailed 10x10 km level, while former retention parameters applied, for example, in Gren

8 The costs are estimated using yield functions, being used to estimate the yield losses from reduced fertilizer application, and subsequently the loss in profits from these lost yields. Yield functions are estimated using Danish experimental data for the dose–response to nitrogen of the 14 crops in clay and sandy soils, and these functions are calibrated to yields and fertilizer application levels in the 8 other countries. A calibrated profit function for each type of crop is constructed from the relevant yield function (Hasler *et al.*, 2012). The reduction in profit that results from a reduction in nitrogen fertilization can thus be calculated as the difference between the profit arising at the reduced level of fertilizer application and the profit arising at an initial, profit-maximizing level of fertilizer application. The costs are obtained by estimating foregone profits due to reduced yields and subtracting the savings in expenditures on fertilizers (estimated by multiplying the price of fertilizers by the reduced amount applied). For this abatement measure, a marginal cost curve can therefore be obtained, where the cost of this measure at a specific location increases the more the application of fertilizers is reduced. This utilizes the detailed information available from catchment models (Andersen *et al.* 2011), and the data and methods used are further described in Hasler *et al.* (2012).

(2008a), Elofsson (2010 b), and Schou *et al.* (2006) used retentions for the 22 drainage basins, and they were not distributed between soil, groundwater and surface water (cf. the description of retentions in Schou *et al.* 2006). As a sensitivity analysis of the effects of different retentions, we have therefore explored the effects of using the MESAW retentions (Stålnacke *et al.* 2011) compared to the "Schou retentions", both retention sets used in BALTCOST, all else being held constant. The MESAW retentions are distributed between soil, groundwater and surface water retention, while the Schou retentions are only measured for surface water. Further details on the assumptions and modeling of the retentions can be found in Hasler *et al.* (2012) and Schou *et al.* (2006).

As a starting point, the effects on the load reduction capacity in the sea regions is compared using the MESAW retentions and the Schou retentions in BALTCOST.

Table 5. Comparison of maximum reduction capacity with the modeled measures in BALTCOST with two sets of retention assumptions

	Max reduction capacity with MESAW retentions		**Max reduction capacity with the "Schou retentions"**	
	N load red. (tonnes/year)	**P load red. (tonnes/year)**	**N load red. (tonnes/year)**	**P load red. (tonnes/year)**
BB	32,037	295	28,644	360
BS	21,804	332	21,649	399
BP	188,933	9,294	309,836	17,108
GF	47,121	2,289	52,993	3,012
GR	40,130	828	55,887	1,371
DS	13,139	406	28,089	874
KT	26,756	679	43,924	1,128
Total	369,920	14,123	541,021	24,252

Hasler et al, 2012 and Schou et al 2006 under the table (table 5).

As the comparison in Table 5 shows, the maximum reduction capacity is higher for phosphorus when using the Schou retentions in all sea basins. The same is true for nitrogen in all the catchments except for the Bothnian Bay and Bothnian Sea, where the BSAP does not assign any nutrient reductions.

The higher maximum reduction capacity is one important explanation for why the costs modeled by Gren (2008 a) and Elofssson (2010 b) are lower than the BALTCOST solutions for the same load reduction targets (BSAP 2007 in HELCOM 2007). The total costs of achieving the Alternative I targets are also compared using the Schou and MESAW retentions in the BALTCOST model. The costs of achieving the BSAP2007 targets are much lower when using the Schou retentions compared to the MESAW retentions: the costs of fulfillment of the full BSAP targets that are achievable when using the Schou retentions are EUR 910 million, which should be compared with the costs of achieving the maximum load reductions that BALTCOST can deliver with MESAW retentions, i.e. EUR 4,680 million.

3.4.4 Sensitivity analysis regarding the effect of changing the distribution of load reduction requirements between sea regions

In Smart *et al.* (2012), a uniform reduction of nitrogen and phosphorus is modeled for all sea basins, i.e. modeling a reduction of 18% in the phosphorus load and 42% in the nitrogen load. This uniform distribution of the targets specified in the original BSAP 2007 for nitrogen and phosphorus (Alternative 1, Table 1) assumes uniform proportions of load reductions in all sea regions. This scenario is neither realistic nor relevant from a natural scientific point of view, but it is economically interesting to compare costs between these two allocative scenarios. This scenario is therefore not a realistic proposal of changes in load reductions between sea regions, but the results shed light on how the total costs depend on the distribution of targets between sea regions.

To model this scenario, the BALTCOST model was used to investigate the feasibility of delivering uniform load reductions of 18% of the incoming N load and 42% of the incoming P load in each sea region (Table 6), which is the load reduction target of HELCOM 2007 for the entire Baltic Sea.

Table 6. Nutrient load reductions (tonnes) representing 18% (for N) and 42% (for P) of the incoming nutrient loads for all Baltic Sea regions

Sea region	Incoming load 1997–2003 (tonnes)		Required load reduction in tonnes (% of incoming load)	
	N	P	N (18%)	P (42%)
BB	51,436	2,585	9,258	1,086
BS	56,786	2,457	10,221	1,032
BP	327,259	19,246	58,907	8,083
GF	112,680	6,860	20,282	2,881
GR	78,404	2,180	14,113	916
DS	45,893	1,409	8,261	592
KT	64,257	1,573	11,566	661

Table 7. N and P reductions delivered by the lowest cost configuration of drainage basin-specific abatement measures attempting to achieve the load reduction targets of Table 6

Sea Region ID	N load red. achieved tonnes) (18% of Alternative 1 target, Table 1)	P load red. Achieved (tonnes) (42% of Alternative 1 target, Table 1)
BB	9,258 (100)	296 (27)
BS	10,221 (100)	333 (32)
BP	58,907 (100)	8,083 (100)
GF	20,282 (100)	2,290 (79)
GR	14,113 (100)	829 (91)
DS	8,261 (100)	407 (69)
KT	11,566 (100)	661 (100)
Total	132,608	12,899

Table 7 reports the load reductions delivered against the load reduction targets of BSAP 2007 (Alternative 1, Table 1) in each Baltic Sea region, within the capacity of the abatement measures modeled in BALTCOST. The total N reduction targets (18%) are achieved in all sea regions by this uniform distribution, but the P reductions targets are not achieved. In fact, only 36% of the P target is achieved, which is less than for the BSAP 2007 HELCOM solution modeled with BALTCOST. This is partly the explanation for why the total costs of fulfilling the load reductions are lower with this uniform distribution than for the HELCOM 2007 distribution.

Table 8. Total annual costs of delivering the nutrient reduction targets of Table 6 using the lowest cost combination of drainage basin-specific abatement measures

Country ID	Total annual cost of nutrient load reductions (EUR million)
SE	347
FI	363
RU	656
EE	97
LV	231
LT	163
PL	379
DK	1,118
Total	3,579

As can be seen from Table 8, the total costs of the uniform distribution are lower than the costs of the BSAP target distribution between sea regions (EUR 3,579 million as compared to EUR 4,689 million).

The comparison between the HELCOM 2007 distribution and the uniform distribution illustrates the large difference that a more uniform allocation of load reductions across the sea regions would make to the distribution of abatement costs between sea regions, and these changes also affect the distribution between countries and measures. The result indicates that it is important to pay attention to the distribution of load reductions between the sea regions, and to the transport between them. Further research is needed in this area.

The sensitivity analysis illustrates that parameters and assumptions such as retentions, land use data availability and use, as well as the assumption of the distribution of load reductions, play important roles in the estimated costs of abatement. The land use and retention sensitivity analyses indicate that disaggregated spatial data improve the models.

3.5 Discussion and conclusions

The costs of achieving the reduced load reduction targets have been estimated using two models: the MTT cost model developed in the PROBAPS project (Ahlvik *et al.* 2014) and the BALTCOST model, developed in the RECOCA project (Wulff *et al.* 2014). The total cost of implementing the BSAP targets from the 1997–2003 load level has been estimated to be EUR 4,680 million. Taking into account the most recent nutrient load data, which are lower than the original reference level, the total cost is significantly reduced. The estimated costs of achieving these targets are EUR 2,340 million per year when modeled with the MTT model, but are lower with BALTCOST, being EUR 1,430 million per year. The differences between the models can be explained by differences in model assumptions regarding the capacities for implementation of the measures, the land-use data used and the model type.

The various results presented in this chapter are subject to many types of uncertainty. Broadly, these can be divided into natural uncertainty (uncertainty regarding the effectiveness of abatement measures), technological uncertainty (uncertain abatement capacity of some measures), and economic uncertainty (uncertainty regarding the cost of abatement measures). Here, we have tried to address the most important uncertainties in the sensitivity analysis (chapter 3.4) and thereby illustrate how our assumptions might drive the costs up or down compared to a "realistic level," e.g.

- The assumptions concerning retention, where the most recent assumptions used by the BalticSTERN models increase the costs compared to the retentions used before.
- The assumptions concerning agricultural production in the catchments, where the simplifying assumption that all crops behave like spring barley in the MTT model tends to overestimate the costs compared to a more realistic assumption of crop distribution.

Many important caveats still remain, however. The models consider a significant number of abatement measures, but many measures are excluded from this analysis. The reasons for not including additional measures are that we do not have reliable data for all relevant measures for all the countries in the Baltic Sea catchment (e.g. storage and management of manure), measures that can be locally very effective but perhaps not useable on a large scale, so that the local specific capacity should be known (e.g. mussel farming and buffer strips). Other measures can be connected to the new potentials of technological innovations. These new measures can, at best, be part of the cost-effective set of measures, and at worst they will have no effect on the optimal solution. Therefore, our restricted set of measures provides an upper bound for the total cost.

Also, it should be noted that our cost estimate is based on a situation where the abatement measures can be implemented without any transaction costs. In reality, these transaction costs can be large, and this will in turn increase the costs beyond our estimate. Some measures can be easier to implement than others. For example, emissions from point sources, such as emissions from wastewater treatment plants, are more easily measurable than agricultural nutrient loading, and the costs of wastewater treatment improvements can be shared by a large number of households, which also reduces the distributional barriers. The transaction costs of agricultural measures are likely to be higher than these costs for the wastewater sector.

Large-scale cost-effectiveness analyses, such as the ones introduced in this chapter, can only have a limited set of measures and large spatial resolution due to computational reasons. To improve the accuracy of cost-effectiveness calculations, one could use spatially more explicit, country- or catchment-specific cost models that can include a larger set of potential abatement measures. The possibility for estimating credible constraints for the capacity of measures and the effects of them on nutrient emissions is also better within models at a more detailed spatial scale.

4. Benefits of improving the state of the Baltic

Main messages:

BalticSTERN analyses provide valuable insights into the importance of the Baltic Sea and its ecosystem services to the general public, revealing how people in the region value improvements in the environmental state of the sea. These findings need to be taken into account in future policy decisions.

Research results show that the majority of citizens living in the nine Baltic countries have visited the sea and many people use the sea for recreational purposes. There is a high general awareness of eutrophication, and many people in the region are worried about the environmental state of the Sea. The majority of the population in the countries surrounding the Baltic Sea are willing to pay for an improved environmental state. The total benefits of achieving the nutrient reduction targets of the BSAP are estimated at around EUR 3,800 million annually.

4.1 Methods and data

Two large-scale surveys were carried out in the BalticSTERN studies to assess the importance of ecosystem services in the Baltic Sea area, and to collect information on the benefits of improving the marine environment.

BalticSurvey identified how people around the Baltic Sea use the sea and what attitudes they have towards the marine environment, and towards various measures for improving the environment. About 9,000 interviews were carried out in 2010 in all nine Baltic Sea countries. A full report of the study is available from Swedish EPA (2010a and 2010b), and further analysis of the data is available in Ahtiainen *et al.* (2013b).

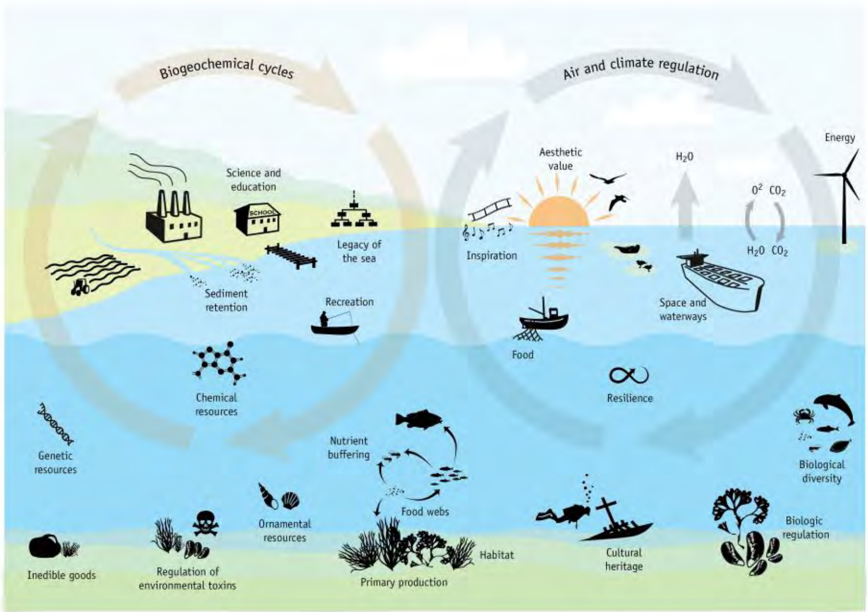
BalticSUN (Baltic Sea Study of Use and Non-use values) investigated the use and non-use values of an improved state of the Baltic Sea with regard to eutrophication. About 10,500 interviews were carried out in 2011 in all nine Baltic Sea countries. The results allowed an estimation of the benefits of reaching the HELCOM Baltic Sea Action Plan (HELCOM, 2007) nutrient reduction targets in monetary terms (Ahtiainen *et al.* 2012 and 2013a).

4.1.1 Ecosystem services and their valuation

The Baltic Sea marine ecosystem provides many services that contribute to human welfare. In addition to market-valued benefits such as the sea's role as a transport route and source of nutrition (fish stocks), there are many benefits that we enjoy but pay no price for. While the most obvious of these have to do with recreational use of the sea, there are also benefits related to the existence of a healthy marine ecosystem (so-called non-use benefits). It is important to recognize the important role such benefits play in our well-being, because eutrophication reduces our possibilities to enjoy them. An estimate of the societal benefits of nutrient abatement is also needed to justify costly nutrient abatement measures (see chapter 3).

Swedish EPA (2008a) identified 24 ecosystem services provided by the Baltic Sea, including primary production, biogeochemical cycling, food production, waterways for transport and shipping, as well as maintenance of biodiversity and resilience. These are illustrated in Figure 4. Some of these services provide direct benefits to human societies, for example clear water for recreation and fish stocks for food. Others are more indirect functions and processes that are essential inputs to several different services and can be, for example food webs, climate regulation and resilience. Figure 4 highlights the complexity of the Baltic marine ecosystem, and the multiple interactions between the sea's services and the benefits they generate. BalticSTERN studies mainly examine recreation and existence benefits, which are affected by several direct and indirect ecosystem services in Figure 4, for example water quality and fish stocks. These are, however, in turn dependent on the functioning of several of the more indirect services shown in the figure, such as nutrient buffering and primary production.

Figure 4. Ecosystem goods and services provided by the Baltic Sea ecosystem

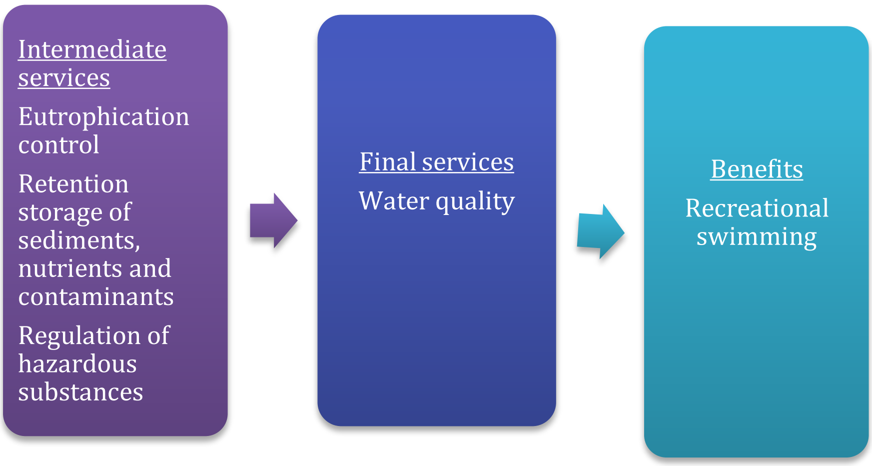


(Illustration: J. Lokrantz/Azote. Source: BalticSTERN 2013).

When attaching economic values to ecosystem services, they are often divided into intermediate and final services, and also separated from the goods or benefits they provide (Fisher *et al.* 2009, Turner *et al.* 2010b, UK NEA 2011). Final services directly generate benefits to people, and intermediate services function as an input to the final services. Changes in the supply of final services are therefore an appropriate basis for monetary valuation. Final services are also usually easier to identify, as they directly link to our well-being. Intermediate services require a much deeper understanding of the dynamics and interactions of the ecosystem in order to be identified. If an attempt is made to directly value the underlying ecological processes that support multiple ecosystem services, there is a risk that the total values might be overestimated due to double counting (Fisher *et al.* 2008 and 2009). There is a risk of double counting when different ecosystem services are valued separately and the values are aggregated, or when an intermediate service is first valued separately, but also subsequently through its contribution to a final service or benefit. For example, part of the value of pollination (intermediate service) is already embodied in the market price of a crop, and cannot therefore be added to the market value (Turner *et al.* 2010b). Focusing on final services in economic valuation is a simplification mainly to avoid double counting. However, not considering underlying functions and processes in the assessment might cause irreversible consequences. For example, the resilience of marine ecosystems is a particular challenge to address (e.g. Mäler 2008, Walker *et al.* 2010).

An example of the division of ecosystem services into intermediate and final, linked to the benefit of recreational swimming, is given in Figure 5.

Figure 5. Example of intermediate and final ecosystem services linked to recreational swimming



There are many issues to consider in the economic valuation of ecosystem services, including spatial explicitness, marginality, non-linearities in benefits, and threshold effects (see Turner *et al.* 2010b for a more extensive explanation). Valuation of ecosystem services is mostly undertaken only at the "margin", and while incremental changes in the flow of ecosystem services have been valued in BalticSTERN, many other valuation studies have focused on valuing the stock of ecosystem services (see e.g. Bateman *et al.* 2011 for a description of the difference between stock and flow of ecosystem services). Valuing marginal changes can be difficult, as there is often a large gap regarding the availability of quantified data on changes in the provision of ecosystem services over time and space under different scenarios. In BalticSTERN research, valuing a marginal change has been crucial, and substantial collaboration between natural and social scientists has made it possible to quantify a change in the water quality in the Baltic Sea due to the implementation of the BSAP nutrient reduction targets. An attempt to value stocks of ecosystem services would not be relevant in this context, since by definition no change in the environmental state is involved in such estimations (Bateman *et al.* 2011).

4.1.2 *Data collection*

Surveys were the primary method of collecting data for the analysis, as no comprehensive statistics on attitudes and recreation in the Baltic Sea area were available. BalticSurvey specifically aimed to outline the recreation habits and general attitudes towards the sea of the region's citizens. The results of the BalticSurvey were then used to help design a more specific survey, BalticSUN, which elicited information on the values of reducing eutrophication using the contingent valuation method. In addition to the valuation question, the BalticSUN survey included questions on the underlying personal attitudes, level of knowledge about the Baltic Sea and eutrophication, and background of each respondent (e.g. income, age, and education). Both surveys were conducted in each coastal country using random sampling for representativeness. Table 9 summarizes the survey methods used, sample sizes, response rates and the age groups contacted in each survey (further information on the implementation of the BalticSurvey is available from Ahtiainen *et al.* 2013b, and BalticSUN from Ahtiainen *et al.* 2012). Face-to-face interviews were used in some countries to improve the representativeness of the population. In the BalticSurvey, the Russian sample covered only the Baltic Sea coastal region, i.e. Kaliningrad and St. Petersburg regions, due to the large size of the country and as the survey aimed to address the uses of the Baltic Sea.

Table 9. Survey methods, sample sizes, response rates, and the age groups surveyed

Country	Survey	Method of survey	Sample size	Response rate (%)	Age of respondents
Denmark	BalticSurvey	Telephone	1,000	13.7	Over 16
	BalticSUN	Internet	1,061	38.2	18–74
Estonia	BalticSurvey	Interviews	1,001	29.5	15–74
	BaltiSUN	Internet	505	42.1	15–74
Finland	BalticSurvey	Telephone	1,007	20.6	Over 15
	BalticSUN	Internet	1,645	39.4	18–74
Germany	BalticSurvey	Telephone	1,000	5.7	Over 15
	BalticSUN	Internet	1,495	32.5	18–70
Latvia	BalticSurvey	Interviews	1,060	45.7	15–74
	BalticSUN	Interviews	701	45.0	18–74
Lithuania	BalticSurvey	Interviews	1,032	46.5	15–74
	BalticSUN	Interviews	617	60.5	15–74
Poland	BalticSurvey	Telephone	1,010	7.7	Over 16
	BalticSUN	Internet, interviews	2,029	36.0 n/a	20–60
Russia	BalticSurvey	Telephone	1,000	41.0	18–64
	BalticSUN	Interviews	1,508	69.3	18–85
Sweden	BalticSurvey	Telephone	1,017	19.7	Over 16
	BalticSUN	Internet	1,003	34.0	Over 18

Both surveys were developed together with experts from each coastal country and translated from an English master copy to national languages. Due to differences in cultures, awareness levels and languages in the study area, it was vital to make the surveys such that their concepts were understood similarly in all countries after translation. For this purpose, the design of the surveys took from several months to over a year with a large amount of pre-testing, including in-depth interviews, focus groups, and pilot studies.

4.1.3 Valuation of reduced eutrophication

Both use values (e.g. recreation) and non-use values (e.g. the existence of a healthy marine ecosystem) could potentially be substantial in the case of an improved state of the Baltic Sea. Therefore, the economic valuation method used in BalticSTERN had to be able to capture both use and non-use values. The importance of both types of values is a particularly applicable consideration in the case of eutrophication in the Baltic, as it affects a unique ecosystem with long time lags between abatement measures and their impacts on water quality.

In economic valuation, only stated preference methods can capture both use and non-use values. Therefore, these methods play a very useful role in cost-benefit analysis (CBA). Stated preference methods are most suitable in cases when significant non-use values are to be assessed, as these values cannot be revealed through any markets (Pearce *et al.* 2006, Turner *et al.* 2010a, Bateman *et al.* 2011).

In the BalticSUN valuation study, the contingent valuation (CV) method was used to estimate the benefits of reducing eutrophication in the Baltic Sea according to the nutrient reduction targets of the HELCOM Baltic Sea Action Plan (HELCOM 2007). Contingent valuation is a survey-based method that elicits individuals' willingness to pay (WTP) for a well-defined environmental change, with willingness to pay representing the benefits of a change in monetary terms. Estimates of mean willingness to pay can be aggregated to provide an estimate of the total benefits at the national and international scale. The CV method was chosen because the valuation was conducted for specific eutrophication reduction scenarios for the cost-benefit analysis, and the aim was also to assess the non-use values of reducing eutrophication in addition to use values.

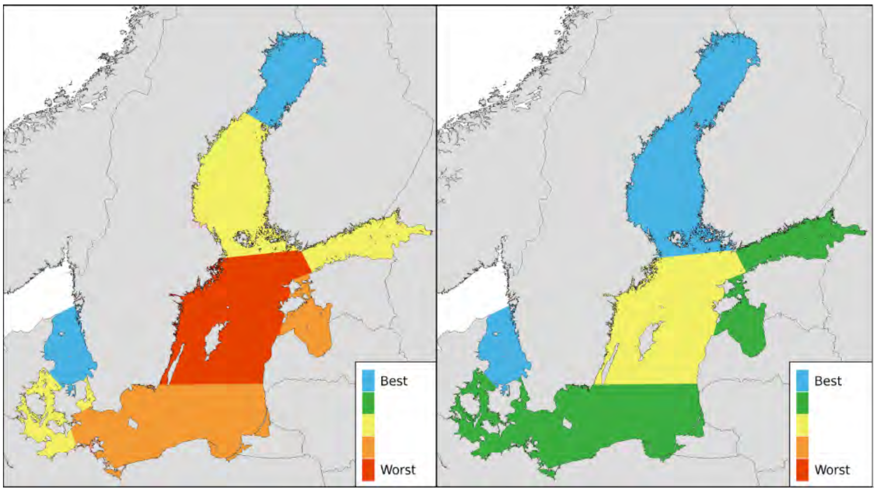
To estimate the benefits of reduced eutrophication in the Baltic Sea, respondents first needed to understand the concept of eutrophication. Therefore, the results from the marine models predicting the future level of eutrophication were adapted into descriptions of linked environmental impacts and visual material to make the changes easy for respondents to understand. Based on the results of marine models (Ahlvik *et al.* 2014), 2050 was selected as the year for which the different levels of eutrophication were presented (see also chapter 2).

The predicted conditions of the Baltic Sea in the year 2050 were illustrated with color maps. Each color was defined using a written description for the associated level of eutrophication. The environmental characteristics associated with each level of eutrophication were described using a water quality scale, which is shown in Table 10. The five-step water quality scale was based on HELCOM's Ecological Quality Ratio (EQR), which represents relationships between the actual status and the reference condition in the Baltic Sea (HELCOM 2009). The descriptions were formulated such that they were appropriate for the entire Baltic Sea region and clearly showed the differences between the levels of eutrophication.

Table 10. Five step water quality table

Description of the effects of eutrophication						
Water quality	*Water clarity*	*Blue-green algal blooms*	*Underwater meadows*	*Fish species*	*Deep sea bottoms*	Water quality
Best possible water quality	Clear	Seldom	Excellent condition Good for fish spawning and feeding	Cod, herring and perch common	No oxygen deficiency Bottom animals common	Best possible water quality
	Mainly clear	Sometimes	Patchy vegetation Good for fish spawning and feeding	Cod, herring and perch common	Oxygen deficiency in large areas Bottom animals common	
	Slightly turbid	In most summers	Cover a small area Less good for fish spawning	Fewer cod, but herring and perch common More roach, carp and bream	Oxygen shortages often in large areas Some bottom animals rare	
	Turbid	Every summer	Cover a small area Bad for fish spawning	Fewer cod, herring and perch More roach, carp and bream	Oxygen shortages often in large areas Some bottom animal groups have disappeared	
Worst possible water quality	Very turbid	On large areas every summer	Almost gone Not suitable for fish spawning	Almost no cod, fewer herring and perch Lots of roach, carp and bream	Oxygen shortages always in large areas No bottom animals in many areas	Worst possible water quality

Figure 6. Level of eutrophication in the Baltic Sea in 2050 with business-as-usual development (left) and fulfillment of the BSAP targets (right)



(Source: Ahtiainen *et al.* 2012).

The change in eutrophication presented to respondents showed improvements in the water quality of the sea based on certain ecosystem characteristics: water clarity, blue-green algal blooms, underwater meadows, fish species, and the state of deep sea bottoms (see Table 10). The benefits people receive from an improved water quality in the Baltic Sea are partly attributable to being able to perform recreational activities, for example bathing and recreational fishing. There are also benefits related to non-use values, such as those arising from the good condition of underwater meadows or deep-sea bottoms.

The survey elicited public willingness to pay for a change in eutrophication related to reaching the nutrient reduction targets in the Baltic Sea Action Plan. A business-as-usual (BAU) eutrophication scenario (non-action scenario) was developed and described, predicting the expected development of nutrient loads and concentrations in the sea if no additional abatement actions were taken. The BAU scenario was then compared with the policy scenario depicting the state of the Baltic Sea where the Baltic Sea Action Plan nutrient load targets were fulfilled. Thereafter, the respondents were asked how much they would be willing to pay each year to obtain a future in which the policy scenario had generated a healthier Baltic Sea compared to the BAU. Figure 6 shows the BAU scenario compared to the scenario corresponding to the implementation of the BSAP with the colored maps based on the water quality scale.

The respondents were told that funds to improve the Baltic Sea would be collected using an ear-marked Baltic Sea environmental tax on each individual and firm in all Baltic Sea countries. Respondents were also reminded that the payment would be yearly and for an indefinite time, that the program would not improve other environmental problems in the Baltic Sea, and also that there are substitute water bodies to the Baltic Sea.

4.2 Results: Use, attitudes and benefits

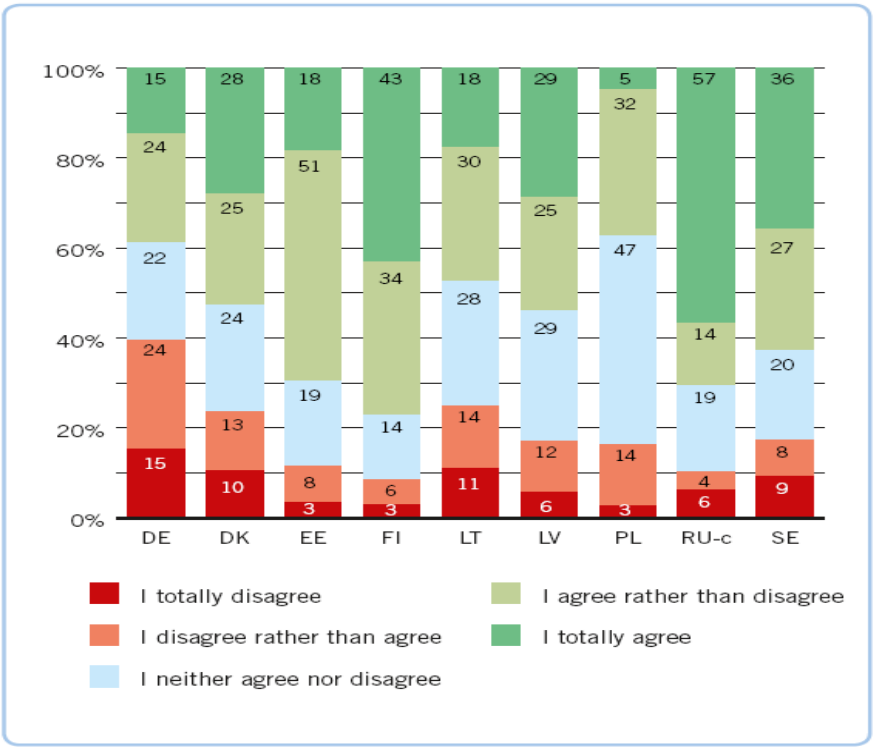
4.2.1 Recreation and attitudes in the Baltic Sea coastal countries

BalticSurvey was the first coordinated study of comparable information in all Baltic Sea countries regarding public use of the Baltic Sea and people's attitudes towards the marine environment, and towards responsibilities for improving the environment. The study provided insights into the importance of the Baltic Sea to the general public and possible public involvement in funding mechanisms to strengthen environmental protection of the sea. Results from the study showed that the Baltic Sea is an important recreation area for people in the region. Based on the results, approximately 37 million people visit the Baltic Sea each year, and about 80% of the survey respondents had at some point spent leisure time at the Baltic Sea. Swedes were the most frequent users in the region (98% of the Swedish respondents had spent time by the sea), followed by Danes and Finns. The most common activities people enjoyed were being at the beach or seashore for walking, sunbathing or similar activities. Swimming, recreational fishing, boat excursions and cruises were also common. These recreational benefits people gain from the sea are, directly or indirectly, dependent on the wide array of ecosystem services provided by the Baltic Sea (shown in Figure 4), and thereby also on how well the marine ecosystem functions (see chapter 4.1). Especially critical for recreational purposes is the capacity of the Baltic Sea to provide good water quality, as many of the activities people enjoy are dependent on this service.

The survey further showed that people are in general highly aware of the eutrophication situation and also of other environmental problems in the Baltic Sea. Many people are also worried about the environmental state of the Sea. Finns were most worried (77%), but even in the countries where people were least worried, i.e. Poland and Germany, over one-third of the respondents indicated worry over the environmental state (Figure 7). Environmental issues pointed out by respondents as being major problems in the Baltic were marine litter, heavy metals and other hazardous substances, small oil leakages, potential large oil spills, damage to marine flora and fauna and algal blooms. Considering there are about 85 million people living in the Baltic Sea catchment area, maintaining the Baltic Sea in a healthy state in the future will become very important (BalticSTERN 2013).

Regarding responsibilities for environmental improvements, the majority of the respondents in the study believed that their own country's wastewater treatment plants, industries, maritime transport, ports, farmers and professional fishermen should take actions to improve the Baltic marine environment. Regarding funding actions to improve the environment, people considered increased charges on pollution emissions to be acceptable. This indicates that there is support in the Baltic region for polluters to bear the costs for their own emissions. Increases in taxes or water bills were not so popular among respondents, although people were in general less negative towards making payments that are paid by everyone and are earmarked for funding actions.

Figure 7. Percentage shares of agreement with the statement "I am worried about the Baltic Sea environment" in different countries



(Source: Swedish EPA 2010a).

4.2.2 Benefits from reduced eutrophication

BalticSUN investigated what the monetary benefits would be to the general public of an improvement in the state of the sea with regard to eutrophication. BalticSUN was the first economic valuation study to cover all the nine Baltic Sea countries, and probably the largest international valuation study to consider improvements to the marine environment and differences in preferences for protecting marine ecosystem services. Results from the study confirmed many of the findings in BalticSurvey, and showed that every second person has personally experienced the consequences of eutrophication, mostly in terms of blue-green algal blooms and water turbidity, and that people attach great value to improving the condition of the Baltic Sea. The majority of citizens in the Baltic Sea countries were willing to pay for reduced eutrophication. In total, the citizens of the Baltic Sea countries were willing to pay around EUR 3,800 million annually to achieve this improvement. As expected, the average willingness to pay varied significantly between countries, as shown in Table 11. On average, Swedes were willing to pay the most for reduced eutrophication, while Latvians were willing to pay the least. Part of these results can be explained by income differences, but cultural, geographical and other factors may also have an effect. The share of the adult population willing to pay at least something for an improvement in the countries was on average over 50% in all countries except Russia and Latvia (Table 11). On a national level, the largest aggregate benefits accrue to the populations of Germany and Russia, mainly due to their large population sizes, and Sweden, due to the Swedes' high average willingness to pay.

Table 11. Aggregate benefit estimates for reducing eutrophication according to the BSAP (in 2011 euros)

Country	Adult population (in millions)	Share of the adult population willing to pay (%)	Annual mean WTP per person (EUR)[a]	National WTP per year for BSAP (EUR million)
Denmark	3.958	52	51.91	205.5
Estonia	0.989	52	17.35	17.2
Finland	3.617	63	55.60	201.1
Germany	68.321	54	27.37	1869.8
Latvia	1.690	48	4.23	7.1
Lithuania	2.516	50	6.32	15.9
Poland	24.624	53	8.57	211.1
Russia	81.467[b]	31	5.80	472.5
Sweden	7.564	67	110.76	837.7
Total	194.746			3837.9

(Source: Ahtiainen *et al.* 2013a).

[a] Conversion to euros using the mean exchange rates in 2011 from the European Central Bank.

[b] Russian population includes the people living in Western Russia, i.e. in the Central, Southern, Northwestern and Volga Federal Districts.

Compared to an earlier benchmark study, the Baltic Drainage Basin Project (BDBP) (see e.g. Söderqvist 1996, Gren *et al.* 1997 Turner *et al.* 1999, and Markowska and Zylicz 1999), the willingness to pay results in BalticSUN are somewhat lower. There are, however, several differences between the two studies. While this study encompasses data from all coastal countries, the BDBP project used data from Sweden, Lithuania and Poland to aggregate willingness to pay to the whole area. Also, the description of the change in eutrophication was different. The time horizon for full environmental effects to emerge was 20 years in the BDBP, in contrast to 40 years in BalticSUN. Finally, the Baltic Sea political, economic and social environments have changed from the early 1990s, the time when the BDBP was conducted, requiring an update for sound policy analysis (BalticSTERN 2013).

It is not surprising that people in the Baltic region attach considerable value to efforts to mitigate eutrophication, as they frequently use the sea and are concerned about the marine environment. BalticSUN also showed that most people not only care about their local areas, but value having the entire Baltic in a healthier state. Many respondents also chose non-use related reasons for stating their willingness to pay in the survey. This indicates the presence of significant non-use values. That is, those who do not use the sea may also attach value to having a healthy sea to pass on to future generations, or may merely take satisfaction from knowing that it will recover from its environmental problems (see e.g. Pearce *et al.* 2006 or Turner *et al.* 2010a for a further description of use and non-use values).

Beyond conventional individual-specific economic values estimated in BalticSUN, there might exist values that are driven by collective or shared responsibility for societal well-being – so-called “shared values” (see e.g. Fish *et al.* 2011). To complement the BalticSUN approach to environmental valuation, and in particular to acknowledge that there may be several ways to measure environmental values, BalticSTERN conducted a small experiment with the objective of identifying whether a “shared value” for the Baltic resource exists and, if so, recording and describing the deliberative process that led to it. The experiment is described in detail in the Background Paper on Shared Values to BalticSTERN (Cole 2013). The experiment found potential shared values regarding the Baltic and its ecosystem services, which are distinct from but supplement the conventional individual values captured in BalticSUN.

4.2.3 Uncertainties

The results of BalticSUN are subject to some uncertainty. In this context, some of the main sources of uncertainty originate from survey responses, sampling, and modeling approaches. The contingent valuation method was chosen due to its capability to assess non-use values and the need to assess the values of specific scenarios.

The design of the valuation survey is paramount to producing reliable benefit estimates. The language was kept as simple as possible to enable uniform translation of the survey to the national languages of the nine countries, and identical surveys were used in all countries to enable comparisons. In a valuation survey, it is vital that the respondents understand the environmental change they are asked to pay for. This requires the researchers to give a certain amount of knowledge to the respondents in a value-neutral way. Thus, the valuation survey was pretested in all countries using focus groups, in-depth interviews and pilot surveys to ensure that the respondents understood the questions similarly in all countries. Researchers gave no value judgment, and there were no significant issues causing protests against the survey. The design and pre-testing phase of the survey took nearly two years.

In the implementation of the national surveys, large enough samples were required to achieve broadly representative sampling over spatial locations and demographics. Survey companies in each country were asked to provide estimates of national population representativeness for an Internet-panel survey. The Internet-panel survey was chosen as the survey method to ensure each respondent saw the same survey. In countries where representativeness was not ensured with Internet panels, personal interviews were opted for. Personal interviews carry the risk of interviewer bias, i.e. that the interviewer affects the survey responses in a systematic way. However, no evidence was found for such bias.

Beyond the data collection-related uncertainties, other sources of uncertainty still exist. The contingent valuation method asks respondents' willingness to pay directly without actual budget restraint, i.e. the respondents are not asked to pay the monetary amounts in reality. This may result in hypothetical bias, meaning the respondents state they are willing to pay more than they would actually pay. Related to this, a survey of experimental literature by List and Gallet (2001) found that experiments with "real" economic commitments tended to produce lower estimates than "hypothetical" ones.

To date, much research has been devoted to the reliability of willingness to pay figures, and the problem of hypothetical bias can be alleviated with careful survey design. In BalticSUN, there was no evidence for people being willing to contribute unreasonable amounts of money. Of those willing to pay, the mean willingness to pay per year was about 0.5% of the annual net income. Less than 11% of the respondents were willing to contribute more than 1% of their annual income (Ahtiainen *et al.* 2012). As a related issue, some of those respondents who refused to pay could still value an improvement in the water quality of the Baltic Sea. For example, some respondents might think that someone else should pay for the improvement, e.g. the polluters, but they would still obtain benefits from the improvement. These so-called "protest" respondents were assumed to have a zero willingness to pay in the study, which lowers the estimated benefits of reducing eutrophication.

Survey-based valuation methods are necessary to be able to include the benefits of environmental improvements in cost-benefit analyses, as it is not possible to estimate the value of these benefits based on market transactions.

4.3 Discussion

4.3.1 What is included in BalticSTERN research on benefits?

Ecosystem service assessments and accompanying economic analyses can, according to Bateman *et al.* (2011), be divided into two types: "sustainability analysis" and "program evaluation". While the first type normally highlights non-sustainable growth patterns up to the present time, the latter analyzes alternative future development strategies. MEA (Millennium Ecosystem Assessment, 2005) and TEEB (The Economics of Ecosystems and Biodiversity, 2009) are probably the largest examples of the first type. The UK NEA (UK National Ecosystem Assessment, 2011) undertakes both types of analysis (Bateman *et al.* 2011). BalticSTERN assessment of the benefits of reduced eutrophication in the Baltic Sea mainly falls within the second type, since the benefits of achieving a policy target, i.e. the nutrient reduction targets in the BSAP, are estimated using scenarios predicting different future developments.

Ecosystem services provided by the Baltic Sea, the benefits they generate, and the economic value of these benefits have been examined previously (Swedish EPA 2008b). The studies in BalticSTERN are, however, the first consistent attempts to describe recreational use, determine the importance of the Baltic Sea in all nine coastal countries, and to estimate the benefits of an improvement in the water quality for all countries. The BalticSUN valuation study furthermore provides a unique outlook on the non-market values of the Baltic Sea in the coastal states and shows that the benefits foregone (or the cost of degradation) would be significant if the nutrient reduction targets in the BSAP are not implemented. Benefit estimates were also designed for use in the cost-benefit analysis, which is unique at this scale. The collected data are the most comprehensive currently existing scientific data on values attached to the Baltic Sea and provide a basis for future research to update and compare the results.

BalticSTERN research results have provided important information on the value of recreation and a healthy marine environment in the Baltic Sea, and this research is the best available knowledge at present. However, it is important to understand that the estimated benefits do not reflect the total value of all Baltic Sea ecosystem services, or even all services related to water quality. The ecosystem services of the Baltic naturally also generate other benefits not linked to reduced eutrophication. For example, water transport is generally not affected by an improvement in the environmental state of the sea. In addition, some benefits linked to reduced eutrophication might not have been captured by the valuation study. Certain economic sectors, such as fishing, tourism, shipping, and energy producers, which also use the sea, may experience profit reductions due to eutrophication. Benefit estimates in BalticSUN do not include market values in general. However, as some of the respondents of the valuation study could have included tourism and fishing in their willingness to pay to some degree, these benefits of reduced eutrophication may, to some extent, have been accounted for. The estimated benefits may thereby partly include a value for these industries, but it is certain that adding the benefits of production and service sectors would increase the total benefit estimate. Studies (e.g. BCG 2013 and HELCOM 2010) have shown that the tourism sector, in particular, is an economically important industry in the Baltic Sea countries. According to BCG (2013), coastal tourism has increased since 2009, despite the recent economic downturn, and drivers behind this include beach tourism, recreational boating, cruise tourism, and recreational fishing (BCG 2013). In future research, it could also be valuable to further investigate how different future scenarios of the environmental state of the Baltic Sea could affect market values.

To maintain a clear focus on the Baltic Sea improvement scenario, spillover benefits to inland waters that accrue from the implementation of policies improving the Baltic Sea were not assessed. Nutrient abatement measures conducted in upstream regions of the catchment area reduce nutrient loads to the Baltic, but may have an even more pronounced impact on the water quality of lakes and rivers, thus affecting human welfare. We know from national freshwater and coastal studies that the benefits from improving groundwater (Hasler *et al.* 2007), as well as inland and coastal water quality can be high (Jørgensen *et al.* 2012, Jensen *et al.* 2013). Thus, nutrient abatement according to the BSAP targets will likely incorporate a larger portfolio of values than the policy originally intended, which means that the benefit estimates in the BalticSUN survey for the sea area are only a partial representation of the societal benefits of nutrient abatement. The experiment in BalticSTERN on the potential existence of shared values also gives further indications that the BalticSUN survey represents only a portion of the total value society holds for affected resources. Furthermore, the current economic downturn affects the results in at least two ways: firstly, people are likely to be more aware of their current income level, thus giving more reliable answers to the willingness to pay question, and secondly, if the economy rebounds, it is likely that people will be willing to contribute more than the current estimate. All in all, it is likely that the benefits of achieving the BSAP nutrient targets are underestimated rather than overestimated.

4.3.2 *Predicting the future*

There is naturally still a gap in fully understanding possible future developments of Baltic Sea ecosystem services, and hence the effect on future benefits, as they do not need to be fixed over time depending on how drivers and pressures evolve in the future. Many of the ecosystem services in the Baltic are already under severe threat. Out of the 24 marine ecosystem services identified by Swedish EPA (2008a), only ten are functioning properly and seven are under severe threat. The main pressures on Baltic Sea ecosystem services are eutrophication, overfishing, physical disturbance, hazardous substances, oil spills, and invasive species. The benefits attained by reaching the BSAP nutrient reduction targets could be endangered by an increase in these environmental pressures on the marine ecosystem of the Baltic Sea. For example, in the case of a large oil spill, some of the benefits could be completely lost.

BalticSTERN scenarios did not include climate change effects, as it was assumed that these effects would not have an impact on the environmental state of the Baltic Sea by 2050. However, recent research within the project ECOSUPPORT indicates that climate change could potentially cause warmer and less saline waters, and that the impacts on the ecosystem may be seen earlier than previously thought (Meier *et al.* 2012). Such effects would most likely in turn increase other pressures on the Baltic Sea mentioned above. The combined effects of pressures may even trigger the ecosystem to pass certain thresholds. Regime shifts of this kind have already happened in the past, and experience shows that such shifts may be difficult to reverse. As there may be non-linearities and not yet completely understood feedback mechanisms in the system, there is even risk for collapse of parts of the ecosystem (BalticSTERN 2013).

Future potential regime shifts may severely influence the ecosystem services, and the estimated benefits of eutrophication mitigation could thereby be jeopardized. One strategy to deal with these uncertainties could be to take actions to strengthen the resilience of the Baltic Sea ecosystem, thus improving the sea's ability to recover from future shocks. Another strategy would be to take a more precautionary approach and assume that the stock of the ecosystem services (i.e. the assets available) of the Baltic Sea is at risk of deteriorating below sustainable levels. Since changes in the state have implications for the benefits derived, high welfare values may thereby be at stake if there are such risks. It would be interesting in future research to further analyze the implications of the combined effects of pressures for the predicted benefits in the future, such as the combined effect of overfishing and eutrophication.

5. Cost-benefit analysis of the BSAP

Main messages:

The overall benefits of implementing the BSAP clearly outweigh the aggregate costs of nutrient abatement provided that the remaining efforts are cost-effectively allocated across alternative measures. This result gives clear support to aim for full implementation of the BSAP. Reconciling the principles of equity and cost-effectiveness in water protection remains an important challenge for future international and national policies.

5.1.1 Applications of cost-benefit analysis in evaluating environmental projects

Cost-benefit analysis is a method to evaluate the desirability of public projects, investments and policies. It also provides an economic criterion for ranking alternative projects. Cost-benefit analysis identifies the main strengths and weaknesses of a proposed project or policy, quantifies them in monetary terms, and weights them to ascertain if and by how much the overall benefits outweigh the costs.

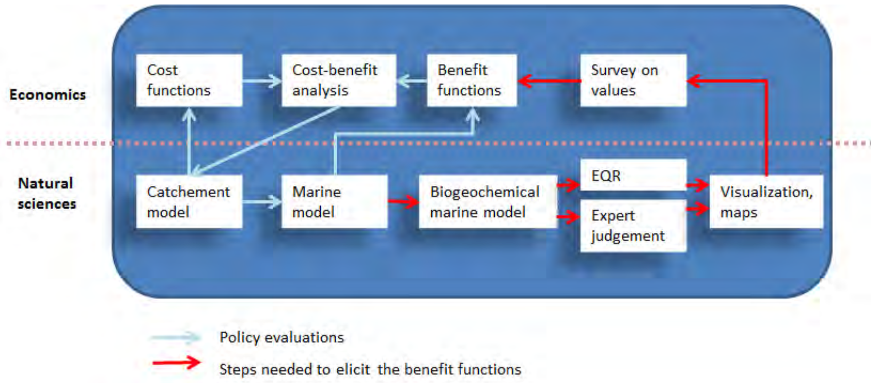
Cost-benefit analysis is a routine process in many countries when evaluating large public projects, such as building roads and harbors, but it can also be used to evaluate large-scale, transboundary environmental projects. The Stern review on climate change (Stern 2007), which estimates the societal costs of climate change, is probably the best-known environmental cost-benefit analysis in the literature.

5.1.2 Ecological-economic framework

The BalticSTERN cost-benefit analysis evaluated the long-term benefits and costs of reducing eutrophication in the Baltic Sea. An integrated assessment modeling framework was created for this purpose (see Figure 8 for the elements of the modeling framework). The analysis looked at the sea and its catchment as a whole and took the point of view of a social planner when analyzing the overall costs and benefits across country boundaries.

As a first step in the analysis, a catchment model was employed to describe the effects of a given combination of nutrient abatement measures on future loads of nitrogen and phosphorus. Cost functions were then used to draw the respective cost projection. Next, a marine model was applied to predict the impacts of nutrient loads on the state of the marine environment. Finally, a benefit function translated the improvements in the marine environment to a monetary estimate of the changes in human welfare. The red arrows in Figure 8 denote those model components (biogeochemical models and survey data on citizens' willingness to pay for improvements in water quality) that were needed to elicit the benefit functions.

Figure 8. Ecological economic framework



More details regarding cost-benefit analysis can be found from the final report of BalticSTERN (2013) and a working paper (Hyytiäinen *et al.* 2013). Details regarding the catchment model, cost function and the marine model can be found in Ahlvik *et al.* (2014) and chapter 3 of this report, and regarding the benefits for reduced eutrophication in Ahtiainen *et al.* (2013a) and chapter 4 of this report.

5.1.3 Results

Table 12 presents the costs and benefits for achieving the remaining nutrient reductions to meet the targets of the BSAP (See Alternative 2 in chapter 2). The cost estimate assumes that the target will be reached in a cost-effective manner (i.e. with the lowest possible cost), and that both basin-wise and country-wise reduction targets will be achieved. The country-wise benefits and costs are expressed as average annual amounts in 2011 euros. The net benefits and the benefit-cost ratios (B/C) describe the economic feasibility of meeting the targets.

Table 12. Benefits and costs of reaching both country-wise reduction targets and maximum allowable loads by sea basin in a cost-efficient manner (EUR million/year)

	Benefits	Costs	Net benefits	benefit/cost
Swe	838	326	512	2.6
Fin	201	49	152	4.1
Rus	473	113	360	4.2
Est	17	36	-19	0.5
Lat	7	123	-116	0.1
Lith	16	134	-118	0.1
Pol	211	752	-541	0.3
Ger	1,870	651	1,219	2.9
Den	205	620	-415	0.3
All	3,838	2,803	1,035	1.4

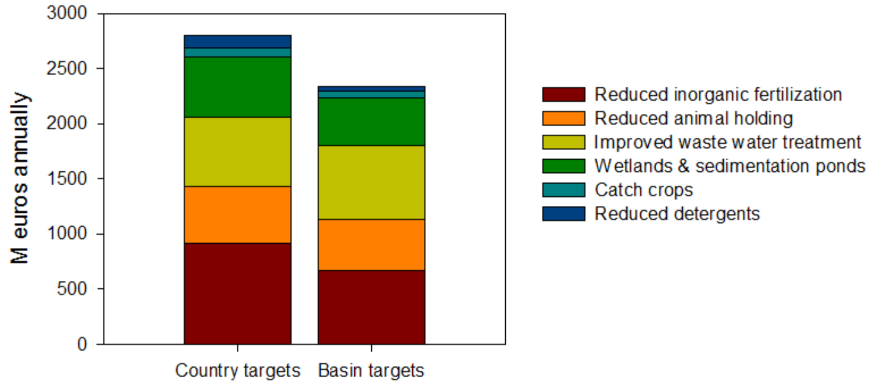
The overall benefits of improved water quality clearly outweigh the costs of meeting the load reduction targets. The welfare gains are considerable (EUR 1,035 million each year). This implies that the Baltic Sea Action Plan is an economically sound transboundary environmental project. The benefits foregone (or the cost of degradation) would be considerable if the BSAP was not implemented.

The benefits of improved water quality clearly exceed the costs of nutrient abatement for Sweden, Finland, Russia, and Germany. However, for other countries, for instance Denmark, the estimated costs of meeting the load reduction targets from HELCOM(2007) are high, and exceed the overall benefits. The high cost level and low benefit level would have changed if i) the cost model included more measures (cf. chapter 2) that would have reduced the total costs, and ii) the benefits to inland waters, groundwater protection (against nitrate), coastal areas and fjords were included. The negative result for Denmark, for example, should therefore be interpreted with this in mind, and with caution.

Cost-effective solutions were also computed to meet only the provisional basin-wise nutrient reduction targets (as shown in Table 3 in chapter 3). The total cost from meeting the basin-wise targets is somewhat lower (EUR 2,336 million annually) than the cost of meeting both country-wise and basin-wise reductions targets (see Table 2). This result implies that there are potentials for cost savings if the load reductions could be coordinated amongst the countries loading their water to the same sea basin.

Figure 9 presents the total annual costs for both objectives (basin & country targets and basin targets only), and how the efforts are optimally divided across different measures.

Figure 9. The cost-effective combination of measures meeting both country and basin targets and only basin targets of the BSAP



5.1.4 Beneficiaries and payers of water protection

The beneficiaries of improved water quality in the Baltic Sea are the citizens, industries and businesses (such as tourism) that enjoy and utilize the services and products the sea provides in all coastal countries. Their possibilities to enjoy a healthy marine environment with all ecosystem services intact would clearly be improved. The costs of nutrient abatement are covered by citizens in the form of increased water charges (investments in wastewater capacity), by farmers (uncompensated agricultural measures), and by taxpayers (environmental support payments).

The aggregated benefits are highest in highly populated regions, while the aggregated costs are highest in regions that drain into the sub-basins that are presently in the most alarming ecological state – in particular the Baltic Proper – and thus are subject to the most ambitious nutrient abatement targets.

5.1.5 Policy conclusions & recommendations

The overall societal benefits outweighing the total costs of nutrient abatement creates a strong incentive to the Baltic Sea countries to aim for full implementation of the Baltic Sea Action Plan. On the other hand, the costs and benefits are unevenly distributed across the riparian countries, economic sectors, and regions. This calls for identification of mechanisms and ways of cooperation and burden sharing to make implementation of the BSAP mutually encouraging for all stakeholders. International financial instruments, such as the Cohesion and Structural Funds of the EU, and joint international projects involving private and public actors as financers are ways to share the costs of nutrient abatement between different stakeholders.

In the BSAP, allocation of load reduction targets across riparian countries is based on the so-called "Polluter Pays Principle". According to this principle, the country-wise load reductions have been made proportional to current loading to each sea basin. The Polluter Pays Principle is widely applied, and a well-justified principle when solving environmental problems. However, this approach does not take into account spatial variability in the unit costs, the availability of different measures, or the effectiveness of measures across different regions. Thus, a solution to a transboundary pollution problem that agrees with the "Polluter Pays Principle" is not necessarily cost-effective (as is demonstrated in Figure 9). Reconciling these two sometimes contradictory principles of equity and economic efficiency remains a challenge, and should be given due consideration in the planning and implementation of national and international water policies.

5.1.6 Caveats and interpretations

While we can anticipate with some confidence the future consequences of our present actions through scenarios, simulations, and projections, the future is ultimately uncertain. Thus, the results of a cost-benefit analysis, like the results of any other quantitative study that looks into the future, must be interpreted with caution.

The most serious omission of our cost-benefit analysis is probably that it does not take into account the positive impacts of nutrient abatement on the provision of ecosystem services and potential benefits in inland waters (see chapter 4.3 for more discussion on caveats regarding benefit estimates). Nutrient abatement conducted in upstream regions of the catchment area reduces nutrient loads to the Baltic, but may have an even more pronounced impact on the water quality of lakes and rivers. In addition, measures such as wetland construction may improve the biodiversity of agricultural lands and the scenic value of landscapes. In this light, the benefit estimate is only a partial representation of the true societal benefits of nutrient abatement.

The costs of nutrient abatement may be overestimated or underestimated depending on the relative importance of different caveats and uncertainties (see chapter 3.4 for more discussion on the sources of uncertainty in the cost models). Overestimation may result from the coarse spatial resolution of the applied model, the limited number of measures examined and the exclusion of possible future innovations and technological developments. The cost of nutrient abatement could be reduced by including more optional measures and developing nutrient abatement plans tailored to each catchment or sub-catchment. There is also room for technological innovations that would provide more effective nutrient reductions in wastewater treatment, agriculture, forestry, industries, shipping, and other relevant sectors causing nutrient emissions. On the other hand, transaction costs, including the administrative costs of planning and enforcing the implementation of agri-environmental policies, were omitted. On balance, it is likely that the costs are overestimated rather than underestimated.

To summarize, the true welfare gains to be expected from future investments in water protection are likely to be clearly greater than indicated by the numbers presented in this report.

6. Potential applications of the data, models and results for decision support

In this chapter, we discuss how environmental economic research conducted in the BalticSTERN research network and the numerical results from integrated assessment of nutrient abatement in the Baltic may serve in the planning, implementation, and evaluation of international and national water policies.

The existing framework can be adjusted and used as a tool to conduct ex-post analysis of the past policies or past phases of the ongoing policies, and ex-ante analysis of the new policies and new revisions of the ongoing policies.

6.1.1 Baltic Sea Action Plan of HELCOM

The BSAP is a major international policy guiding water protection in the riparian Baltic Sea countries. The BSAP is being developed in an iterative process and is periodically revised based on the latest advances in water protection and research information. So far, the focal components of the treaty, the country-wise and basin-wise load reduction targets, have been based on proportional load reductions and ecological arguments. Next, we discuss the insights economic research results can provide in the implementation of the existing targets and in the planning of future targets.

The cost-and-effect models developed in the BalticSTERN network (Hasler *et al.* 2012, Ahlvik *et al.* 2014) and in other corresponding studies (Gren 2008 a,b, Elofsson 2010 a,b) are designed to identify cost-effective combinations of nutrient abatement measures between sectors and locations. Such information may help the riparian Baltic Sea countries to consider how to allocate nutrient abatement efforts across different economic sectors and regions and to identify opportunities for cost savings. In further revisions of the BSAP, cost-and-effect models may also be used in the design and planning of country-wise or regional nutrient reduction targets in search of solutions that meet both the equity and cost-effectiveness considerations in balanced proportions. Economic models, if developed at an adequately detailed spatial resolution and with reliable data, may help to identify cost-effective combinations of nutrient abatement measures between sectors and locations.

Survey data on the uses of the sea and values people place on improvements in water quality can be used to evaluate and justify further investments in water quality. Comparison between the overall costs and benefits also makes it possible to investigate whether the costs of some proposed measures are disproportionally large in comparison to the benefits or the costs of some other, alternative measures. Such comparisons provide decision makers with guidance on how to allocate the available funds in the best possible manner.

The benefit and cost functions of nutrient abatement can also be combined in optimization models that are used to determine the socially optimal level of water protection and the corresponding, cost-effective spatial and temporal allocation of measures. Results from such optimization models, if based on adequately reliable data, may give guidance to the societal decision makers on the appropriate level of water protection.

6.1.2 EU Marine Strategy Framework Directive

The aim of the European Union's Marine Strategy Framework Directive (adopted in June 2008) is to more effectively protect the marine environment across Europe and to achieve the full economic potential of oceans and seas in harmony with the marine environment. It aims to achieve a Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. Each Member State must draw up a program of cost-effective measures by 2015, and before implementation of any new measure, an impact assessment needs to be conducted, which includes a cost-benefit or cost-effectiveness analysis of the proposed measures.

The integrated assessment framework developed within the BalticSTERN program for analyzing the costs and benefits of nutrient abatement provides a tool to address one specific Good Environmental Status (GES) descriptor, i.e. eutrophication, but also addresses other descriptors that depend on the eutrophication status of the Sea. The framework can be adjusted and applied to relevant parts of other European regional seas where eutrophication is considered to be an environmental problem. It is also possible to accommodate other GES descriptors in the modeling framework provided that research information and models describing the causal interactions between the marine ecosystem and society are available.

6.1.3 The EU Water Framework Directive

The EU Water Framework Directive is another major international water policy guiding the management of inland and coastal waters, as well as groundwaters. To meet the requirements of the Directive, the member states are, amongst others, obliged to create River Basin Management Plans, which are the primary tools of nutrient abatement in EU countries. The Water Code of the Russian Federation is an equivalent policy in Russia.

The River Basin Management Plans are required to be revised at six-year intervals. During each revision, there are opportunities for introducing new tools that can help identifying cost-effective nutrient abatement measures and programs. The requirements for using the sound principles of cost-effectiveness analysis also apply to the implementation of the WFD in the river basins, and cost-benefit analysis might be used to inform the identification of disproportionate costs. While cost-effectiveness analysis is a requirement, the use of tools for disproportionality analysis is not so clear, and cost-benefit analysis is therefore an option, not a requirement. Thus, the frameworks developed and presented in the present report for the entire Baltic Sea and its catchments may be used in the construction of integrated modeling frameworks for smaller areas, to evaluate the economic consequences of different nutrient abatement measures or strategies at the catchment level. However, the spatial resolution of such models should be more detailed and tailored to each specific River Basin Management Plan.

6.1.4 The EU Nitrates Directive

The EU Nitrates Directive protects water quality across Europe by preventing nitrates from agricultural sources polluting groundwater and surface waters. The directive has been operational for over 20 years, and the member states have planned and implemented a large number of action programs over the past 20 years. The action plans focus on setting upper limits for the application of organic and chemical fertilization, and thus reducing the flow of nitrates to groundwater and surface waters in the designated nitrate vulnerable zones. The coverage of these sensitive areas varies considerably across the riparian Baltic Sea countries. In some countries, such as Finland and Denmark, entire catchment areas draining their waters to the Baltic Sea are designated as sensitive areas, while in some other countries only a proportion of the land area is classified as nitrate vulnerable zones.

The upper limits of nitrate inputs to the soil, as specified in the national implementation of the nitrates directive, are accounted for in BalticSTERN analyses as measures already accomplished. However, the cost-and-effect models developed here could be used in ex-post analysis of the economic consequences of past and ongoing restrictions.

6.1.5 National environmental and agricultural policies

Integrated assessment tools and models specified for the entire Baltic Sea region may also help in the planning and evaluation of national policies. The models can be used, for example, to demonstrate the ecological and economic impacts of measures conducted in one country relative to the planned water protection efforts conducted in neighboring countries. The models can also be used to demonstrate the lags related to measures conducted in different sectors.

7. Conclusions

Economic research on water resource management can serve as a salient tool when planning, designing, and evaluating international and national water management plans and policies. In this regard, the three most important conclusions from BalticSTERN's research are:

- The overall ambition of the Baltic Sea Action Plan to reduce eutrophication in the sea is economically viable. The expected societal benefits from improved water quality clearly outweigh the total costs of nutrient abatement.
- The citizens in the Baltic Sea region attach considerable value to the improved health of the sea. More than 80% of the people living in the area have spent leisure time at or on the sea. Many of them are deeply concerned about the Baltic.
- Collaboration across coastal countries and sectors and acknowledging spatial variability in the costs and effectiveness of nutrient abatement are the keys to cost-effective nutrient abatement.

The conclusions are therefore that the additional efforts to reduce eutrophication, as agreed on in the HELCOM Baltic Sea Action Plan, are worthwhile. The benefits of improved water quality clearly exceed the costs, and give support to the implementation of the BSAP.

The results of a cost-benefit analysis, like the results of any other quantitative study that looks into the future, must be interpreted with caution, however. The most serious omission of our cost-benefit analysis is probably that it does not quantify the positive impacts of nutrient abatement on the provision of ecosystem services and benefits in inland waters. Nutrient abatement measures conducted in upstream regions of the catchment area reduce nutrient loads to the Baltic, but may have an even more pronounced impact on the water quality of lakes and rivers. In addition, measures such as wetland construction may improve the biodiversity of agricultural lands and the scenic value of landscapes. In this light, the benefit estimate is only a partial representation of the true societal benefits of nutrient abatement.

The costs of nutrient abatement may be overestimated or underestimated depending on the relative importance of different caveats and uncertainties. Overestimation may result from the coarse spatial resolution of the applied model, the limited number of measures examined and the exclusion of possible future innovations and technological developments. The cost of cost-effective nutrient abatement could be reduced by including more optional measures and developing nutrient abatement plans tailored to each catchment or sub-catchment. There is also room for technological innovations that would provide more effective nutrient reductions in wastewater treatment, agriculture, forestry, industries, shipping, and other relevant sectors causing nutrient emissions. On the other hand, transaction costs, including the administrative costs of planning and enforcing the implementation of agri-environmental policies, were omitted. On balance, it is likely that the costs are overestimated rather than underestimated. To summarize, the true welfare gains to be expected from future investments in water protection are likely to be clearly higher than indicated by the numbers presented in this report.

The BSAP is a major international policy guiding water protection in the Baltic Sea. The plan is an iterative process and is periodically revised based on the latest advances and research information on the need for new actions. Economic research, such as the results from the BalticSTERN research network presented here, can assist HELCOM in identifying economically efficient ways to improve the state of the Baltic as a unique and jointly managed natural resource. Economic models, if developed at an adequately detailed spatial resolution and with reliable data, may help to identify cost-effective combinations of nutrient abatement measures between sectors and locations. Socio-economic research on the present or desired uses of the Baltic Sea and its importance to people's welfare can, together with ecological criteria, be used to set future target levels for water protection.

The EU Marine Strategy Framework Directive poses a serious challenge for socio-economic research on marine areas by requiring member states to conduct cost-effectiveness and cost-benefit analyses related to the programs of measures aimed at improving the state of the European regional seas. The integrated assessment framework developed within BalticSTERN network for analyzing the costs and benefits of nutrient abatement provides one tool to address one specific Good Environmental Status (GES) descriptor, i.e. eutrophication, but also addresses other descriptors that depend on the eutrophication status of the Sea. The framework can be adjusted to and applied in relevant parts of other European regional seas where eutrophication is considered an environmental problem. It might also be able to accommodate other GES descriptors, provided that research information and models describing the causal interactions between the marine ecosystem and society are in place.

The EU Water Framework Directive is another major international water policy guiding the management of inland and coastal waters and nutrient abatement in EU countries. The Water Code of the Russian Federation is an equivalent policy in Russia.

Economic models developed and the data collected in the network, as well as in other corresponding projects, may be used as tools in the implementation, evaluation, and revision of the BSAP and other international environmental policies such as the EU's Marine Strategy Framework Directive. It is, however, important that the practitioners of such models are well aware of the limitations and uncertainties related to the particular model used, and careful in interpreting the model results in the light of these caveats. This report has attempted to elaborate some of such caveats related to research tools used in the BalticSTERN research network as an inspiration for the further use of environmental economic research results in decision making.

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9. Svensk sammanfattning

Denna rapport sammanfattar och diskuterar resultat från BalticSTERN, ett internationellt forskarnätverk som genomför ekonomiska analyser av pågående och framtida möjliga insatser för att minska övergödningen i Östersjön. Denna rapport kompletterar en tidigare sammanfattande rapport av BalticSTERN ”Worth it: Benefits outweigh costs in reducing eutrophication in the Baltic”, publicerad som ett av underlagsmaterialen inför HELCOM’s Ministermöte i Köpenhamn i oktober 2013.

Forskarnätverket BalticSTERN har undersökt hur invånarna i Östersjöländerna skulle värdera en förbättrad vattenkvalitet enligt målen i HELCOM’s Aktionsplan för Östersjön, Baltic Sea Action Plan (BSAP). BalticSTERN har även beräknat kostnaderna för kostnadseffektiva kombinationer av åtgärder för att minska närsalter till havet enligt BSAP. Kostnadsnyttoanalysen som beskrivs i denna rapport har beräknat de ekologiska konsekvenserna och de långsiktiga ekonomiska nettovinsterna av BSAP. Denna rapport analyserar hur robusta dessa monetära resultat är genom modelljämförelser, känslighetsanalyser samt identifiering av osäkerhetsfaktorer.

Resultaten visar att de aggregerade nyttorna av att genomföra de föreslagna närsaltsreduktionerna klart överstiger de aggregerade kostnaderna, vilket tyder på att BSAP är en samhällsekonomiskt lönsam plan för att lösa de gränsöverskridande övergödningsproblemen i Östersjön. Kostnaden av att inte vidta ytterligare åtgärder, dvs. att inte uppfylla målen i BSAP, skulle bli betydande. De verktyg som har utvecklats av forskarnätverket inom BalticSTERN kan stödja beslutsfattande och ge underlag för planering, design och utvärdering av framtida internationella och nationella vattenförvaltningsplaner och strategier för Östersjön.

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Nordic Council of Ministers

Ved Stranden 18
DK-1061 Copenhagen K
www.norden.org

Environmental economic research as a tool in the protection of the Baltic Sea

This report reviews the findings of an ecological/economic analyses regarding the on-going and prospective efforts to reduce eutrophication of the Baltic Sea, conducted by BalticSTERN, an international research network.

The results indicate that the overall benefits of fulfilling the targets of the HELCOM Baltic Sea Action Plan (BSAP) clearly outweigh their aggregate costs, suggesting that the BSAP is an economically sound plan for solving the transboundary eutrophication problem. The cost of inaction - not implementing the objectives of the BSAP - would be significant.

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