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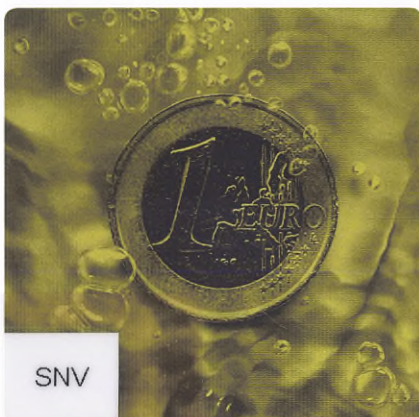
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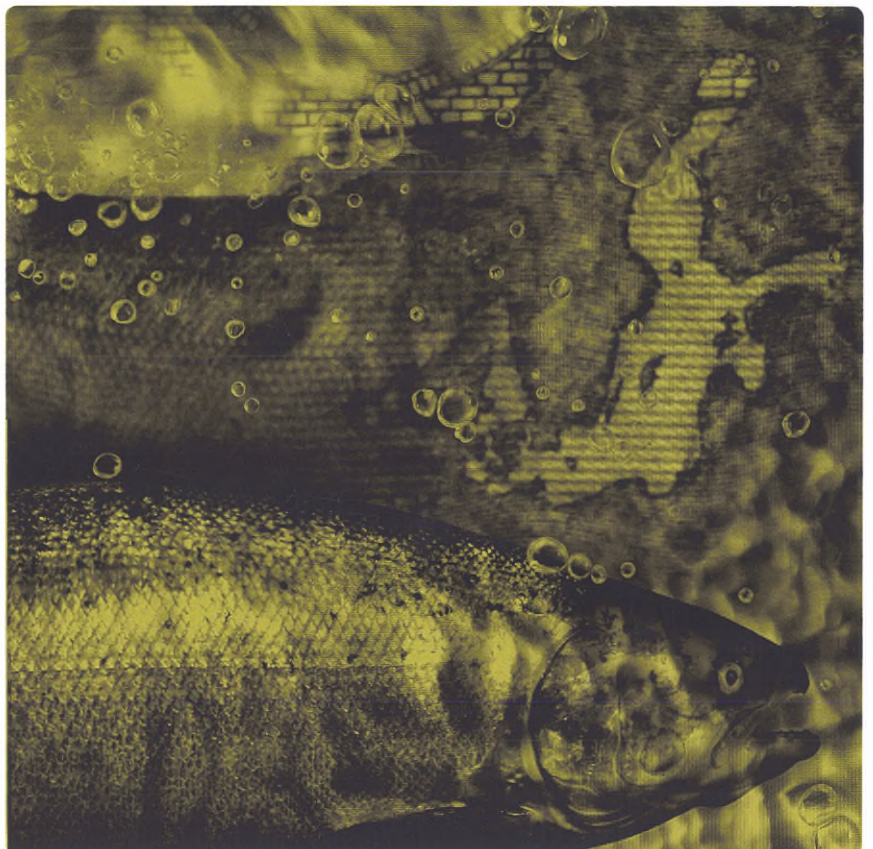
The costs of environmental improvements in the Baltic Sea and Skagerrak

A review of the literature

REPORT 5876 • DECEMBER 2008



SNV





The costs of environmental improvements in the Baltic Sea and Skagerrak

A review of the literature

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Preface

The Swedish Environmental Protection Agency, by assignment of the Swedish Government, has carried out a project, led by Katrin Zimmer to gather information about the economic impacts of the human influence on the Baltic Sea and the Skagerrak¹ environment. The project, based on already existing material, attempts to compare the situation if no further measures are implemented compared to if further measures are implemented. The countries around the Baltic Sea have been invited to participate in the project and the search for economic marine information has been carried out in every state that borders the Sea.

The goal of the project is to provide decision makers with the information available regarding the economic benefits of ecosystem services, the cost of measures required to protect these services, as well as the estimated costs of non-action.

The assignment was divided into different subprojects which resulted in different reports.

1. Report 5873 Ecosystem services provided by the Baltic Sea and Skagerrak
2. Report 5874 The economic value of ecosystem services provided by the Baltic Sea and Skagerrak - Existing information and gaps of knowledge
3. Report 5875 Trends and scenarios exemplifying the future of the Baltic Sea and Skagerrak - Ecological impacts of not taking action
4. Report 5876 The costs of environmental improvements in the Baltic Sea and Skagerrak - A review of the literature
5. Report 5877 Costs and benefits from nutrient reductions to the Baltic Sea
6. Report 5878 Tourism and recreation industries in the Baltic Sea area - How are they affected by the state of the marine environment? - An interview study
7. Report 5879 Economic information regarding fisheries

Each of the reports 1-5 contains information on knowledge gaps and suggestions of new research or how existing information could be compiled.

All subprojects have been compiled into one synthesis report with the title What's in the Sea for me – Ecosystem Services of the Baltic Sea and Skagerrak. (Report 5872)

The report was financed by the Swedish Environmental Protection Agency. Opinions expressed in this report are those of the author and do not necessarily reflect the official view of the Swedish Environmental Protection Agency.

Stockholm, June 2008 Swedish Environmental Protection Agency

¹ The project defines the Baltic Sea and the Skagerrak as the waters of the Bothnian Bay, the Bothnian sea, the Gulf of Finland, the Gulf of Riga, the Baltic Proper, the Danish Straits, the Kattegat and the Swedish coast of the Skagerrak.

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Summary

Large environmental improvements cannot be reached without costs to society. Recognition of cost-effective strategies is fundamental for decisions makers who want to reach environmental targets without wasting society's resources on unnecessarily expensive abatement programs. In this report, the costs of improved environmental conditions in the Baltic Sea and the Skagerrak are discussed. Thus, costs of different measures are related to the environmental effects of the same measures. The review covers studies on reductions of eutrophication, hazardous substances and oils spills and prevention of alien species introduction.

A number of studies on the costs of reducing nutrient loads have been published in the last 15 years. Of those a handful analyze cost-effectiveness on a Baltic-wide scale. The results in these studies suggests that wetland restoration, reductions in fertilizer use, improved manure management and improved wastewater treatment are low-cost measures for nitrogen. For phosphorus, reductions at wastewater treatment plants are emphasized in the studies, complemented by wetlands and phosphate-free detergents. The studies point out Poland, Latvia and Lithuania as countries that have small incentives to participate in a cost-effective or cooperative solution unless other countries compensate them. Sweden and Finland seem to be the main winners from Baltic-wide nutrient reductions when no compensations are made between countries. The results from the studies cannot readily be compared with regard to the costs for achievement of old or new HELCOM targets. However, the most recent study estimates the minimum costs of a 50 % reduction in nitrogen loads, equal to the earlier HELCOM target, to approximately 2.8 Billion EUR per year. Achievement of the new HELCOM target is calculated to between 2.6 and 5.0 Billion EUR per year.

Systematic investigations of the costs of reducing the levels of hazardous substances in the Baltic Sea or Skagerrak are not available. Yet there are studies regarding the costs of e.g. treatment of contaminated sediments, abatement of heavy metals and a ban on TBT (tributyltin) that might serve as a point of departure for future work in this field. Studies on costs of heavy metals abatement, applied in other parts of the world, do however with few exceptions ignore pollutant transports, decay, release and bioaccumulation. Therefore, measures at the sources cannot be compared with measures in the recipient with regard to cost-effectiveness. For TBT, a couple of studies sketch the costs and benefits of a ban, while discussing also the role of TBT for the risk of alien species introduction.

A reduction in oil spills is one of the aims of HELCOM. The damage from oil spills can be reduced through reductions in the probability of an oil spill or through oil spill clean ups after a spill has occurred. The probability of an oil spill can be reduced through *a*) improvements or re-localization of transportation lanes that reduce the probability of collisions and grounding or *b*) increased control efforts that reduce the incentives for deliberate oil spills and the risk for oil spills due to

negligence. Once an oil spill has occurred, the cleanup is almost never complete. Thus, when considering ex-post cleanups as an abatement option it is necessary to take into account also the environmental damage that may occur even after a cleanup operation.

Introduction of non-native species is a threat to Baltic Sea biodiversity which is difficult to manage by available methodologies. Ballast water exchange and a step-wise application of onboard ballast water treatment systems can however reduce the numbers of organisms per ballast water volume unit. Although estimates of the costs of such ballast water systems can be found, the effect of the measure cannot be determined and therefore the measure cannot be compared to alternative actions to improve or protect sea biodiversity. The difficulty to quantify effects makes cost-effectiveness analysis with regard to the objective to strengthen and protect sea biodiversity more difficult.

Research needs

For eutrophication, there is a need to analyze robustness with regard to cost estimations and the associated allocation of costs on countries and measures. In particular, the role of *a)* agricultural policies and markets and *b)* climate change and climate policies for nutrient emissions as well as for costs of nutrient reductions are of interest. In addition, the implementation costs associated with policies at international, national and regional level need to be further analyzed. For hazardous substances, there is a need to link economic activities and the costs for changes in these activities to the corresponding impact on environmental targets. This type of work might only be possible at a smaller scale to start. For maritime activities, both research that provides a framework for comparison of costs and effects of different types of actions as well as research that explores the costs and effects of certain measures can lead to further insights with regard to the cost-effectiveness of different policy strategies. For oil spills as well as for alien species-introduction, the use of a probabilistic framework seems to be motivated. For oil spills, there seems to be a good potential to develop the economic research with applications to the Baltic Sea region, considering the work done on the subject in other parts of the world. Analysis of cost-effectiveness with regard to biodiversity requires integration of ecological and economic research.

Sammanfattning

Stora miljöförbättringar kan inte uppnås utan kostnader för samhället. Beslutsfattare som vill uppnå miljömål utan att slösa bort samhällsresurser på onödigt dyra åtgärdsprogram måste kunna identifiera kostnadseffektiva strategier. I rapporten redogörs för kostnader att förbättra miljöförhållandena i Östersjön och Skagerrak. Kostnaderna för olika åtgärder jämförs med deras effekter på miljön. Genomgången omfattar studier kring minskad övergödning, miljöfarliga ämnen och oljeutsläpp, samt åtgärder för att förhindra att främmande arter tillåts etablera sig.

Under de senaste 15 åren har det publicerats ett antal forskningsrapporter kring kostnaden för att minska närsaltsutsläppen. Av dessa analyserar en handfull kostnadseffektivitet för hela Östersjöområdet.

Resultaten i studierna antyder att återställande av våtmarker, minskad användning av gödningsmedel, förbättrad gödselhantering och förbättrad avloppsrening är åtgärder som till låg kostnad kan minska kväveutsläppen. För fosfor betonas minskade utsläpp genom avloppsrening, kompletterat med våtmarker och fosfatfria tvättmedel. Studierna pekar ut Polen, Lettland och Litauen som länder med svaga ekonomiska motiv för att delta i kostnadseffektiva eller kooperativa lösningar, om de inte kompenseras av andra länder. Sverige och Finland tycks vara de främsta vinnarna när det gäller internationellt samarbete kring minskad övergödning i Östersjöområdet i ett läge då ingen compensation sker mellan länderna. Forskningsresultaten kan inte jämföras på ett enkelt sätt när det gäller kostnaden för att uppnå gamla eller nya HELCOM-mål. Den senaste rapporten uppskattar dock att minimikostnaden för en 50-procentig minskning av kvävemängden, lika med tidigare HELCOM-mål, stannar på cirka 2,8 miljarder EUR per år. Att uppfylla det nya HELCOM-målet beräknas kosta mellan 2,6 och 5,0 miljarder EUR per år.

Systematiska undersökningar av kostnaderna för att få ner nivåerna av miljöfarliga ämnen i Östersjön eller Skagerrak finns inte tillgängliga. Det finns dock kostnadsstudier av till exempel behandling av förorenat sediment, minskning av mängden tungmetaller och ett förbud mot TBT (tributyltenn), som kan fungera som utgångspunkter för framtida arbete inom det här området. Kostnadsstudier av tungmetallreduktion genomförda i andra delar av världen ignorerar dock med några få undantag spridningen av föroreningar i naturen, nedbrytning, utsläpp och lagring i biomassa. Därför kan åtgärder vid källan inte jämföras med åtgärder vid recipienten när det gäller kostnadseffektivitet. För TBT finns det några studier som indikerar kostnader och nytta med ett förbud, samtidigt som de tar upp dess roll när det gäller risken för att främmande arter ska kunna etablera sig.

En minskning av oljeutsläppen är ett av HELCOM:s mål. Skadorna från oljan kan reduceras genom en sänkt sannolikhet för att oljeutsläpp ska inträffa eller genom saneringsåtgärder efter det att utsläppet har skett. Sannolikheten för att oljeutsläpp

ska ske kan minskas genom a) förbättringar och omläggningar av transportvägarna för att minska risken för kollisioner och grundstötningar eller b) ökade kontrollinsatser för att minska incitamenten för avsiktliga oljeutsläpp eller risken för utsläpp på grund av oaktsamhet. När ett oljeutsläpp har inträffat fullföljs nästan aldrig saneringen till hundra procent. När man därför överväga sanering som reduceringsåtgärd är det nödvändigt att beakta de miljökador som kan inträffa också efter sanering.

Introduktionen av främmande arter är ett hot mot Östersjöns biologiska mångfald som är svårt att hantera med hjälp av tillgängliga metoder. Utbyte av barlastvatten och ett system för behandling av barlastvattnet ombord kan dock minska antalet organismer per volymenhet barlastvatten. Även om det går att hitta kostnadsuppskattningar för sådana barlastvattensystem kan åtgärdernas effekt på biologisk mångfald inte bedömas och därmed kan de inte heller jämföras med alternativa åtgärder för att förbättra eller skydda havsmiljöns biologiska mångfald. Svårigheten i att beräkna effekter försvårar generellt analysen av kostnadseffektivitet med avseende på målet att stärka och skydda havsmiljöns biologiska mångfald.

Forskningsbehov

När det gäller övergödningen finns det ett behov av att analysera tillförlitligheten av resultaten i gjorda kostnadsuppskattningar och den tillhörande kostnadsfördelningen mellan länder och åtgärder. Intressanta frågor för fortsatt analys är också a) jordbrukspolitiken och marknaden för jordbruksprodukter och b) klimatförändringarna och klimatpolitiken och den betydelsen de har för närsaltsutsläppen och kostnaderna för att minska dessa. Dessutom behöver de implementeringskostnader som hör samman med politiken på internationell, nationell och regional nivå analyseras ytterligare. För miljöfarliga ämnen är det nödvändigt att koppla samman ekonomiska aktiviteter med kostnader för förändringar i dessa aktiviteter och motsvarande inverkan på miljömålen. Den här sortens arbete kan till en början eventuellt bäst bedrivas i mindre skala. För de maritima aktiviteterna kan forskning som ger ett ramverk för jämförelser av kostnader och effekter hos olika slags åtgärder, liksom forskning som studerar kostnaderna och effekterna hos enskilda åtgärder, leda till ytterligare insikter kring kostnadseffektivitet. För både oljeutsläpp och introduktion av främmande arter tycks användandet av ett ramverk för sannolikhetsberäkning vara motiverat. För oljeutsläpp tycks det finnas en god potential för att utveckla den ekonomiska forskningen inriktad på Östersjöregionen med tanke på det arbete inom ämnet som genomförts i andra delar av världen. Analysen av kostnadseffektivitet med hänsyn till den biologiska mångfalden kräver integrering av ekologisk och ekonomisk forskning.

Introduction

Large environmental improvements cannot be reached without costs to society. Recognition of cost-effective strategies is fundamental for decisions makers who want to:

- reach environmental targets without wasting society's resources on unnecessarily expensive abatement programs. Unnecessarily large expenditure on one environmental target implies that smaller resources will be available for other environmental and social purposes.
- obtain the maximum environmental impact from a given budget. Governments at different levels have limited budgets and they probably want to achieve as much good as possible with the resources available.
- determine whether the net benefits of a planned policy or project are positive. To do this it is necessary to know not only the costs of the policy or project but also the benefits.

In this paper, the costs of improved environmental conditions in the Baltic Sea and the Skagerrak are discussed. Of particular interest for decision makers that care about costs is the relationship between the costs and the effects of a measure or policy strategy. When costs can be compared to the impact on a pre-specified environmental target, one can draw conclusions about the cost-effective strategy. When costs can be compared to the benefits that are associated with the resulting environmental improvement, it is possible to determine the net value of a strategy.

The aim of this paper is to review existing studies on cost-effective strategies to improve the environmental situation in the Baltic Sea and Skagerrak. The review is mainly based on applied studies of mainly scientific character, implying that purely theoretical studies are not included. The review is focused on the role of the scope of study, such as e.g. the geographical area, the target formulation and the number of sectors included, and the methods for calculation of cost-effective solutions to environmental targets. When possible, low and high cost measures are identified. The economic incentives for participation in international agreements are discussed. Gaps in knowledge are identified and suggestions for future research are presented.

There are several limitations to this review. Firstly, it does not include the costs of implementation of policy instruments. This is not to say that policy instruments are not important in this context, the choice and mix of environmental policy instruments can have significant implications for the costs of pursuing environmental policies (see e.g. OECD, 2007). The choice of policy instrument and system for compliance control can be important determinants of the social costs of achieving environmental targets. Secondly, the review does not include measures to restore fish stocks. Thirdly, reports that are focused solely on the costs for different measures without simultaneously including effects are not covered in the review. An

exception to this is made when studies that cover both costs and impacts are missing, such as is the case for e.g. oil spills and hazardous substances.

With these aims and limitations, the review comes to include mainly studies concerning the costs of eutrophication, where the number of studies made is relatively large. For other environmental problems, such as oil spills and hazardous substances, there is basically no literature available that is applied to the Baltic Sea and Skagerrak and the literature applied to other parts of the world is sparse. Therefore, it is not possible to compare the methodological approaches and results with a view on the environmental targets for the Baltic Sea and Skagerrak. In these cases, the review concentrates instead on discussing the state of the art. Based on the review, suggestions are made for further research.

Definitions

Before turning to the actual review some concepts used in the paper need to be defined. By 'measure' is meant the physical changes in technology and human activity needed to improve the environment and not the policy instruments that can be introduced in order for these physical or technological changes to take place. 'Measure' and 'action' are used synonymously. The 'targets' that are discussed are either environmental targets decided upon by national or international authorities or different interpretations of these targets that are made in the literature. Environmental targets decided upon by decision-makers are usually either broad and general, giving a picture of the environmental state, or operative in the sense that improvements in the targets can be measured and, at least in some cases, linked to the activities that are the direct target of policy decisions, such as emissions, investments and management practices. An 'environmental target indicator' is an indicator, by which the degree of fulfillment of the environmental target can be measured. Environmental target indicators can be based on operative targets decided upon by decision-makers, but might also be chosen by the researcher in order to interpret broader and more general targets.

The cost concepts discussed in this chapter are the total and marginal cost of achieving a particular improvement in an environmental target. While the concept 'total cost' is easily understood, it could be worth mentioning that the 'marginal cost' is the change in total cost that arises when the environmental target is changed by one unit, that is, the marginal cost can be interpreted as the cost for the last measure that must be undertaken in order to reach the environmental target. The marginal cost is of particular interest to decision makers as it contains important information for the design of policy instruments such as e.g. environmental taxes. The costs referred to in this report are in 2007 year value. For older reports, costs have been recalculated to 2007 year value using the Swedish CPI as reported by Statistics Sweden and the average exchange rates in 2007 according to the Swedish Riksbank.

One geographical clarification seems also necessary: by the 'Baltic Sea' is, in the following, meant the Baltic Sea including Kattegat and the Danish Straits. Accordingly, Sweden is then surrounded by the Baltic Sea and the Skagerrak.

What is cost-effectiveness and are models necessary?

Cost-effectiveness implies that environmental targets are reached at minimum cost to society. This means, roughly, that the cheapest measures should be implemented first, followed by successively more expensive measures until the target is fulfilled.

The marginal cost for each measure is defined by the cost of the measure at the source and the impact that the measure has on the chosen environmental target. The larger the impact is on the environmental target, the lower is the marginal cost and vice versa. A cost-effective allocation of measures requires that the marginal cost to reach a particular target is equal for all measures. If this does not hold, then it would be possible to reallocate resources from more expensive to cheaper measures such that the environmental target could be reached at a lower cost.

For environmental problems where the alternative abatement actions are few and the impact on the environment is independent of the location and timing, low cost abatement strategies may be identified in a relatively simple manner through straight-forward comparison of abatement costs at different sources. If, however,

- abatement options are manifold,
- the environmental target is demanding,
- different polluting activities are linked through technology, common resource use or markets or
- nature's response to the quantity, location and timing of abatement is complex,

then it becomes necessary to use models to evaluate how total and marginal abatement costs are affected by these factors.

What information is necessary to evaluate cost-effectiveness?

Three steps are necessary in order to define a cost effective allocation of measures. The first is to interpret the politically determined environmental target into a measurable target indicator if the original target is broadly defined. The second is to calculate costs of measures at the sources and the third to quantify the impact of measures at the target. In particular, information about the impact of measures on the environmental target is often hard to find. One reason is that in existing studies, based on natural science, impacts do often not relate to measures for which costs can be calculated, such as changes in the relative shares of different land uses. Also, there is often limited scientific knowledge about the impacts, the qualitative

impact may be known, i.e. one may know whether the impact is positive or negative, but it may not be possible to say how large the impact is.

How should costs be calculated?

When investigating costs related to changes in technology or behavior, cost estimates should, ideally, be a measure of the resources that society has to give up because of this physical change in order to reach the environmental target. This cost is the so-called opportunity cost, i.e. the cost associated with pursuing one action, which contributes to the targeted environmental improvement, in lieu of another, that leads to other benefits to society. The opportunity cost is thus the loss of benefit when a resource is not used in the way that gives the highest value. When calculating the opportunity cost one should, ideally, take into account the value of all side-effects of a measure, such as e.g. the impact of a measure on other environmental targets or the effects on other sectors in the economy through so-called general equilibrium analysis. In practice, this is only done to a limited extent because of the difficulty to find or calculate all the relevant effects. Instead, cost calculations often build on partial inclusion of the factors that determine the "true" social costs.

These 'partial' cost estimates can be calculated in different ways. The simplest way is to use information about investment, operation and maintenance costs. This gives the so-called engineering cost, which is commonly used as a proxy for the opportunity cost in applied studies. There are also a number of different ways to investigate the cost of profits foregone through analysis of market demand and supply.

When large efforts are necessary to reach a target, the cost of a unit reduction is likely to increase with the effort. Methods that reveal the role of increasing costs for each measure therefore give more realistic cost functions. Yet, with a large number of abatement options, the marginal costs with regard to improvements in a particular environmental target indicator will be increasing even if the marginal cost is constant for each single measure. In this case the marginal cost function will increase in a stepwise manner. A simple illustration of such a stepwise marginal cost function and the associated total cost function is given in figure 1. From this figure, one can see that the total cost function increases continuously with abatement, although the speed of increase will change when a new measure is introduced. The marginal cost function increases stepwise, and the introduction of a new measure implies that the marginal cost jumps up to a new level. In most cost-effectiveness models, there are many measures included, so there are many steps in the marginal cost function.

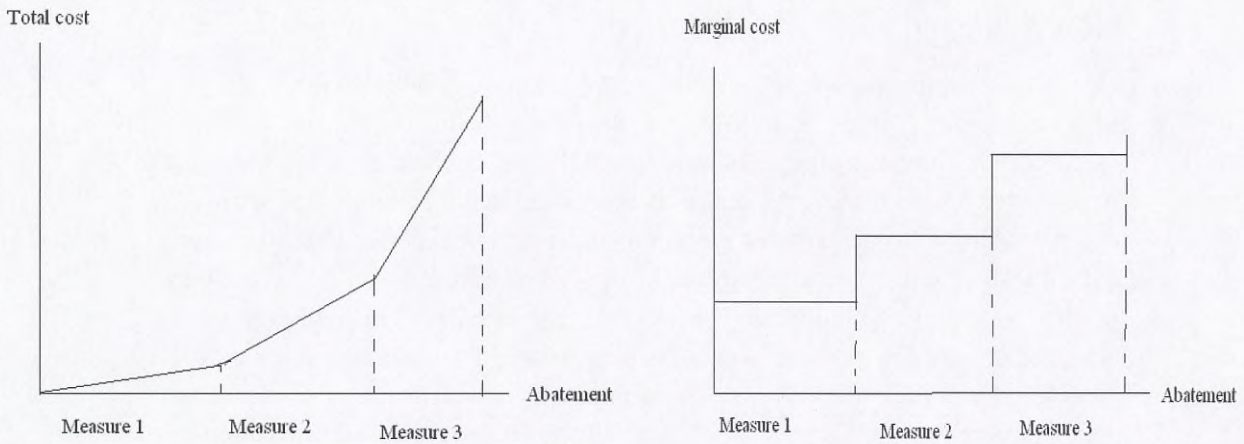


Figure 1. Total and marginal cost functions when each measure has a constant marginal cost.

Summing up, studies that are used as a basis for policy decisions need to be evaluated with regard to their predictive quality. This predictive quality with regard to the cost functions depends e.g. on the number of measures included, whether social costs are taken into account and whether marginal costs are increasing for each measure. However, as said before, the definition of the environmental target, the modeling of the impact of measures on this target and assumptions made on scale, timing and uncertainty also are important to the overall predictive quality of a model.

The environmental targets

The studies in this review are grouped according to environmental objectives of the HELCOM Baltic Sea Action Plan, BSAP (HELCOM, 2007c). Considering that HELCOM targets are broadly defined, it could be assumed that targets for Skagerrak are similar. The four objectives in BSAP are to reach a Baltic Sea unaffected by eutrophication, undisturbed by hazardous substances, with environmentally friendly maritime activities and with a favourable conservation status of Baltic Sea biodiversity: The objectives are presented in larger detail in Box 1. Costs associated with the achievement of these targets are, in the following, discussed for reductions in nutrient loadings, hazard substances, oil spills and invasive species.

Box 1. Environmental objectives of the HELCOM Baltic Sea Action Plan, BSAP.

1. Towards a Baltic Sea unaffected by eutrophication

The plan's objectives for eutrophication include concentrations of nutrients close to natural levels, clear water, natural levels of algal blooms, natural oxygen levels, and natural distributions and abundance of plants and animals.

2. Towards a Baltic Sea undisturbed by hazardous substances

The ecological objectives set out are: to reach concentrations of hazardous substances close to natural levels, to ensure that all Baltic fish is safe to eat, to safeguard the health of wildlife, and to reach pre-Chernobyl levels of radioactivity.

3. Towards a Baltic Sea with environmentally friendly maritime activities

Apart from aiming at reduced emissions to air and water from shipping, the objective is to reduce the risk of pollution accidents at sea, such as e.g. oil spills, abolish illegal discharges and avoid introduction of invasive species due to releases of ballast water and the fouling of hulls into the aquatic environments.

4. Towards favourable conservation status of Baltic Sea biodiversity

This target is strongly linked to the three targets above. Eutrophication and hazardous substances have an impact on biodiversity and intensified shipping adds to existing environmental stress by potentially introducing invasive non-native species and increasing the probability of oil spills. Some species are directly threatened by overfishing or the destruction of their habitats by e.g. dredging and construction along shores.

Eutrophication

Eutrophication is a major problem in the Baltic Sea (HELCOM, 2007c). Eutrophication is caused by high nutrient concentrations which stimulate the growth of algae. This leads to reduced water quality, demonstrated by, e.g., extensive blooms of potentially toxic cyanobacteria that are a nuisance to bathers and others searching recreation along the coasts of the Baltic Sea. In addition, the decay of algae leads to oxygen deficit in the deepwater and thereby also damages biodiversity in the Baltic Sea.

The cause of eutrophication is the excessive nitrogen and phosphorus loads, coming mainly from land-based sources, within the Baltic Sea catchment area. About 75 % of the nitrogen load and at least 95 % of the phosphorus load enter the Baltic Sea via rivers or as direct waterborne discharges. About 25% of the nitrogen load reaches the sea as atmospheric deposition (HELCOM, 2007c).

A number of studies analyze the costs of nutrient reductions to the Baltic Sea. This section starts with an overview of studies that cover most of the Baltic Sea drainage basin, followed by studies on the costs of reductions to the Skagerrak. This is followed by a discussion of the results and the needs for future research.

Baltic-wide studies

Baltic-wide studies of the costs of reducing nutrients to the Baltic Sea have been carried out by e.g. Gren, Elofsson and Jannke (1997), Ollikainen and Honkatukia (2001), Schou et al. (2006), COWI (2007) and Gren (2008). These studies cover the countries adjacent to the Baltic Sea, see figure 2. The paper by Gren, Elofsson and Jannke (1997) has been followed by several papers that develop the analysis building on the same basic structure and these interrelated papers are therefore discussed in connection with each other. The aim is here to compare and assess the results from these studies.

The first Baltic-wide study: Gren, Elofsson and Jannke (1997)

The first large-scale study that analyses minimum costs of reductions of nitrogen and phosphorus to the Baltic Sea was published in 1997 (Gren, Elofsson and Jannke, 1997). The study covers the countries adjacent to the Baltic Sea. The Baltic Sea drainage basin is divided into 14 different regions. Some countries such as Sweden, Finland, and Poland are divided internally along catchment borders, while Russia is divided according to administrative borders and remaining countries each constitute one region. The associated technical report (Gren, Elofsson and Jannke, 1995) reveals that the study includes in total 15 different types of measures, whereof several affect both nitrogen and phosphorus emissions. The measures are in the agricultural, sewage treatment plant, energy and transportation sectors. More than half of the measures are found in the agricultural sector.



Figure 2. The nine countries surrounding the Baltic Sea and the seven major marine basins.

The costs for catalysts in cars and ships and installation of cleaning technologies in stationary combustion sources are calculated as the engineering costs. For reductions in livestock, the cost is that of profits foregone. Costs for land use changes are calculated as the loss of profit when not cultivating the most profitable crop in the region. For improvements in manure management, the costs are based on e.g. investment and timeliness costs. Costs of fertiliser reductions are calculated based on observations from the fertilizer market, using econometrically estimated demand functions. These demand functions are used to calculate losses of consumer surplus for fertiliser consumers, and the costs thereby captures farmer profits foregone. Costs for reductions of nutrient emissions from wastewater treatment plants, for

wetland construction and reductions in fossil fuel use are estimated econometrically².

The marginal cost is constant for all measures except for fertilizer reductions and fossil fuel use. Costs are in nearly all differentiated between the regions in the model.

The environmental target in the study is defined as a reduction of the total load of nitrogen and phosphorus to coastal waters. Costs for different reduction levels are compared. The nutrient transport model, which describes the impact of measures on coastal loads, allows for interdependence between measures e.g. as the amount of airborne nutrient deposition and fertilizer application affects the effect of land use changes: the smaller is the deposition and application of nutrients, the smaller is the effect of land use changes on loads to coastal waters. Retention in soils, inland waters and wetlands are assumed to be constant fractions of the incoming nutrients, i.e. more nutrients are retained if the incoming load is larger. Airborne emission transports are linear in emissions. This implies that they are independent of the amount of reductions in airborne emissions.

Results show that a reduction of nitrogen loads by half³, corresponding to a reduction by 360 kton per year, would cost approximately 1,600 million EUR per year if a least-cost strategy is pursued, see fig 1. A proportional cut in phosphorus emissions, equal to a cutback by 18.5 kton, could be made at a cost of 350 million EUR. The authors estimate that a coordinated nitrogen and phosphorus reduction policy would lead to cost savings that are in the order of 0.4 million EUR per year when both nitrogen and phosphorus loads should be reduced by 50 %, compared to uncoordinated strategies⁴. The reason for this saving is that land use changes, livestock reductions and wetlands all lead to simultaneous reductions of both nitrogen and phosphorus, implying that these measures have a cost advantage.

Calculations also show that a policy with uniform, proportional reduction targets for all countries around the Baltic Sea, will imply 4 times larger costs than the cost effective solution for both nitrogen and phosphorus when nutrient are reduced by 50 %, i.e. approximately 5,500 million EUR. Results suggest that 5 countries would lose under a cost-effective nitrogen policy, and 6 would lose under cost-effective phosphorus policy, see table 3.

² Econometrics combines economic theory with statistics to analyze and test economic relationships. Econometric estimations of cost functions implies that data are collected, and analyzed through econometric methods to derive relationships between costs and measures.

³ A reduction of nutrient loads by 50 percent was the earlier target agreed upon by the HELCOM countries, which explains why this level is used in several studies. Lately, this target has been replaced by provisional targets for each basin, see HELCOM (2007c).

⁴ A coordinated strategy is one where both nitrogen and phosphorus reductions from a measure are considered simultaneously, whereas an uncoordinated strategy is one where, say, the cost-effective strategy on nitrogen is decided through an analysis where only nitrogen is included, and then, the same is done for phosphorus.

Results show that wetlands, increased wastewater treatment and reductions in agricultural loads each account for one third of the nitrogen load reduction when loads are reduced by half. For phosphorus, measures at wastewater treatment plants account for two thirds of the reductions. The remainder of the phosphorus reductions is explained by reduced agricultural load and wetland construction.

It is not self-evident that neither a proportional policy⁵ nor a cost-effective policy leading to a 50 percent reduction in total load, would lead to a situation without symptoms of eutrophication in the Baltic Sea. Based on the results in Gren, Elofsson and Jannke (1997)⁶, Neumann and Schernewski (2005) compare the impact on the Baltic Sea of proportionally reduced and cost-effective reductions, respectively. Their simulations show that for both strategies, reductions in nitrogen and phosphorus loads would mainly affect coastal waters, but favour blooms of blue-green algae in the central Baltic Sea. With the cost-effective approach, blue-green algae blooms would increase even more in the northern part of Baltic Proper. The main difference between the policies would be that coastal regions in the southern part of the Baltic Sea benefit from the larger load reductions in this part of the sea in the cost-effective scenario. In total, the differences between the strategies are considered not to be very large.

Studies with links to Gren, Elofsson and Jannke (1997)

As noted above, measure coverage is an important for the results of cost-effectiveness studies. This is clearly seen when comparing Gren, Elofsson and Jannke (1997) to a study by Elofsson (1999), where cost-effective reductions in the loads of nitrogen to Baltic Sea coastal waters from the agricultural sector and waste-water treatment plants are investigated. This study is used as input in Gren, Elofsson and Jannke (1997), wherefore the methods for calculation of cost functions as well as the nutrient transport model are, basically, the same. When comparing, one can note that in Gren, Elofsson and Jannke (1997), 400 kton nitrogen are abated at a cost of 1,600 million EUR, while in Elofsson (1999), 130 kton are abated at a cost of 1,400 million EUR. Thus, the inclusion of wetlands in Gren, Elofsson and Jannke (1997) makes a large difference with regard to the total cost estimate. One can note that results also show that if each country is required to reduce its load by 50 percent, the total cost will increase by nearly 60 percent compared to the cost-effective solution and that three out of nine countries around the Baltic Sea would gain from uniform reduction targets for the agricultural sector, while all others lose from such a policy, see table 3.

Uncertainty seems to be an unavoidable component when it comes to decisions on policy strategies for large-scale eutrophication. One question is then how policy design can be adopted to account for uncertainty. Extending the study from 1999, Elofsson (2003) analyses cost-effective reductions of stochastic agricultural loads

⁵ where all countries reduce their loads by half

⁶ or rather a popular version where the main contents of this study are presented (Gren, 2000).

to the Baltic Sea. The major difference compared to the 1999 study is that the role of annual load variations for the cost-effective solution is analysed. The reason for considering load variations can be e.g. if these variations imply larger environmental damage over several years than if loads always were at the average level. The environmental targets are expressed as a requirement that nitrogen and phosphorus loads should each be reduced by a certain amount with a given probability, where both the load reduction and the probability are assumed to be chosen by the policy maker. One example would be if policy makers require that loads should be halved with 80 percent certainty, which is the same as saying that loads are halved or more at least 8 years out of 10.

Results in this study show that if agricultural loads of both nutrients to the Baltic Sea should be reduced by half⁷ and policy makers only care about average loads then the cost would be 1,200 million EUR per year. If, instead, loads should be halved with 80 percent certainty, the cost increases to 1,600 million EUR, while a requirement for 95 percent certainty, which is a level often used in statistical analysis, increases costs to 2,000 million EUR. The reason for the higher costs is that more abatement must be undertaken in order to be 'on the safe side'. This causes costs to rise rapidly. At the same time reductions in more variable emissions get a cost advantage compared to reductions in less variable emissions. The reason is that decision-makers are assumed to dislike load variations and measures that reduce both average load and load variation then become particularly attractive. Still, results show that the ranking of measures with regard to cost-effectiveness remains largely unaffected when accounting for load variations. This is because the value of the impact of variation is not large enough to change the ranking, although there are changes in the relative importance of different measures. Fertilizer reductions account for the largest share of nitrogen load abatement followed by reductions at wastewater treatment plants. For phosphorus, reductions at wastewater treatment plants strongly dominate in the cost-effective solution.

Earlier HELCOM targets were expressed in terms of load reductions. However, marine research has shed light on the importance of nutrient transports between different basins in the Baltic Sea and the role that the physical and biogeochemical properties of each basin has for these transports. As the eutrophication problem differs in magnitude between different basins, this information can be highly valuable if policy makers want to direct measures towards the locations with the largest problems. Gren and Wulff (2003) use the model in Gren, Elofsson and Jannke (1997), and extend it by including a marine model, developed within the MARE research program, that is used to calculate both the immediate and the final impact on each basin in the Baltic Sea from changes in loads to any of the basins⁸. In addi-

⁷ Baseline agricultural loads in the model are 257 kton nitrogen and 7 kton phosphorus per year.

⁸ This is done applying so called input-output analysis to the nutrient budget of the Baltic Sea.

tion to this, coastal retention⁹ is accounted for. Because the Baltic Sea is characterized by long water and nutrient residence time¹⁰, large parts of the nutrients are transported among basin. This is shown to play a large role for the design of cost-effective abatement strategies because nutrient emitted to the sea can be transported far away to other basins. In the study, minimum costs for reducing final loads of nitrogen to Baltic Proper and phosphorus to the Gulf of Finland are calculated¹¹. The authors investigate how policy conclusions will depend on assumptions about marine transports and three different policies are compared; (1) where all scientific knowledge on the impact of measures is used, (2) where only the immediate impact of transports between basins is accounted for and (3) only loads from the same catchment can be included in the abatement strategy and marine transports are disregarded.

Results show that a 50 percent reduction of total nitrogen loads to the Baltic Proper, corresponding to a reduction by approximately 6,000 kton per year, can be achieved at a minimum cost of 3,400 million EUR per year when all knowledge on marine transports is taken into account. A policy that aims at the same target but where only the immediate effects of marine transports are recognized would be estimated to cost more than 45,200 million EUR. Thus, costs would be overestimated if only the immediate effects were taken into account, because the effects are larger in the longer run, due to different biochemical processes in the sea. If only measures in the same catchment are included, the target cannot be reached for Baltic Proper. For less stringent targets, the difference between policies is smaller. When the target is a reduction of phosphorus by 50 percent to the Gulf of Finland, corresponding to a reduction by approximately 130 kton per year, this target can only be reached with the first strategy, i.e. the target can only be achieved in a longer run when biochemical processes have augmented the effect of reductions to the coast. The authors conclude that accounting for the final impact on basins may, in principle, imply higher or lower costs for reaching load reduction targets compared to when only the direct impact is accounted for. Whether the costs become higher or lower depends on whether internal biochemical processes in the sea augment or weaken the effect of reductions in coastal loads. If this is the case or not depends on the target basin chosen. However, when all marine transports are accounted for, more basins are linked to the target basin, and hence, there is a larger possibility that measures located at a long distance from the target basin can be included in the abatement strategy.

One might wonder whether actual nutrient policies are similar to or different from the cost-effective strategies. Using the model in Gren, Elofsson and Jannke (1997) as a baseline, Elofsson and Gren (2003) compare Swedish policies from 1995 until the early 2000's. They conclude that policies aiming at nitrogen reductions have

⁹ Coastal retention expresses the amount of nutrient remaining in coastal waters and never reaching the high sea.

¹⁰ The residence time is the time that nutrients remain in the sea.

¹¹ The choice of nutrient to focus on is here based on the so called limiting nutrient, which is the nutrient that controls primary production in these basins.

reduced coastal loads by approximately 13 percent in the period considered. This reduction would be cost-effective in an international context if the international target would have been either a 33 percent reduction of total loads to coastal waters south of Åland Sea¹² or a 27 percent reduction of the total loads reaching Baltic Proper. The cost for the reduction undertaken is estimated to be 3 times higher than what would have been the case if the policy were cost-effective. Correspondingly, with the same budget, a reduction of Swedish coastal loads by 35 percent or of final loads to Baltic Proper by 25 percent could have been achieved. The reasons for the national inefficiencies are both the choice of measures and their geographical distribution. Results show that measures in the Bothnian Bay drainage basin can be cost-effective in a Swedish policy aiming at improvements in Baltic Proper in spite of the long distance to the recipient. The reasons are low costs of some measures in this region in combination with low retention in the drainage basin. Moreover, measures undertaken against airborne nitrogen emissions, such as e.g. installation of catalyts in cars, are expensive if their sole purpose is improvements in sea water quality. Hence, these measures must contribute beneficially to other policies, such as e.g. air quality, if they are to give positive net benefits for society.

One way to compare the incentives for cooperation for different countries is to compare the costs of a cost-effective strategy to those of a uniform reduction policy, such as in e.g. Gren, Elofsson and Jannke (1997). However, the benefits associated with different abatement strategies are also of importance for the view that countries take on. Incentives for international cooperation is often analyzed using so called game-theoretic analysis, where the full cooperation solution can be compared to countries incentives to act in their own interest. In this setting, so called free-riding can be problem. Free-riding occurs e.g. when many countries contribute to pollution of a common resource, because countries have the possibility to gain from abatement actions in other countries without undertaking any action on their own. Based on the cost functions in Gren, Elofsson and Jannke (1997), Gren (2001) compares internationally coordinated actions with national strategies. This is made including estimates of benefits of nutrient reductions from Söderqvist (1996, 1998) and Markovska and Zylicz (1996). The paper shows that the net benefits would be five times higher under a cooperative strategy compared to a situation where free-riding is an option. If benefits of nutrient abatement are the same in all countries per unit of nitrogen, then there would be no net losers under a coordinated policy. This is an unusual outcome compared to most studies of this type. If benefits are not uniformly distributed, then this is not likely to be the case. Results suggest that with different benefits, Poland, Estonia, Latvia, Lithuania and Russia would lose under a cooperative strategy compared to one where each country acts in its own interest, see also table 3.

¹² This reflects the Swedish national target.

Basing cost estimates on investment data - Ollikainen and Honkatukia (2001)

Ollikainen and Honkatukia (2001) analyse the costs of reaching the 50 percent reduction targets for nitrogen and phosphorus to the Baltic Sea, while including all countries adjacent to the sea. They compare cost-effective policies with policies with proportional load reductions. Abatement costs for different countries are estimated econometrically based on data compiled by HELCOM in prefeasibility studies regarding abatement projects for current and former hotspots together with data on actual investment. The results indicate that the total costs of a 50 percent nitrogen reduction, corresponding to a reduction by 429 kton, would amount to 113,000 million EUR, when reductions are proportional in all countries. The corresponding phosphorus reduction, entailing a reduction by 35 kton, would cost almost 9 billion EUR. If, instead, reductions are made in a cost-effective manner, nitrogen and phosphorus abatement cost would amount to 15,200 and 900 million EUR, respectively. The authors note that high marginal costs can be found in countries that have larger resources for abatement, where more abatement has been undertaken already, while countries with low marginal cost have smaller funds and that this dilemma affects the possibilities to reach international agreements. A comparison between the proportional and cost-effective reduction scenarios suggests that four countries would lose under cost-effective policies for nitrogen and phosphorus, respectively, compared to one with proportional reduction, see also table 3.

Collecting recent cost information - Schou et al. (2006)

Schou et al. (2006) present a cost-effectiveness model for the countries adjacent to the Baltic Sea. The model is divided into 24 regions, but most cost functions are calculated on national level for the 9 countries included. In total, 10 different measures are included in the model whereof 5 in the agricultural sector, 1 at wastewater treatment plants and 4 against NO_x-emissions.

Costs for wetland construction are estimated econometrically using Danish data. Costs of reductions in fertilizer use are calculated based on farmers' optimal level of fertilisation. For these two measures increasing marginal costs are used in the model. For other measures, constant marginal costs are used. Catch crop costs are based on engineering costs estimates. For livestock reductions, the costs are the profits foregone. The cost of NO_x reductions are calculated based on engineering costs for 4 different measures. All measures are assumed to be independent with regard to the environmental impact on the Baltic Sea.

Calculations are made to estimate the minimum cost of reducing nitrogen loads to the Baltic Sea coastal waters by approximately 160 kton. The cost is computed assuming there are separate targets for coastal loads to all marine basins, which can be expected to imply higher costs compared to a single target for the whole basin. The total cost for the chosen reduction is estimated to 804 million EUR. The authors suggest that reductions of NO_x-emissions in the energy sector, fertilizer reductions and catch crops can be made at low cost, while livestock reductions are expensive.

Compiling costs for a broad set of measures - COWI (2007)

On behalf of HELCOM and NEFCO, the consultant COWI has produced an analysis (COWI, 2007) of costs and effects of alternative actions against eutrophication in the Baltic Sea and the role of these actions for different policy scenarios suggested by the BSAP. All countries adjacent to the sea are included. In some of the policy scenarios Norway, Belarus and the Czech Republic are also included.

The report includes calculation of costs of nitrogen and phosphorus reductions at waste water treatment plants, through reduced use of phosphate free washing detergents, livestock reductions, conversion of agricultural land into grassland, wetland construction, catch crops, reduced fertilizer use, improved manure management and NO_x reductions for stationary combustion sources, heavy vehicles and ships. In total, 16 measures are included, whereof 5 at wastewater treatment plants, 1 against phosphate free detergents, 7 in the agricultural sector and 3 against NO_x-emissions. The cost used for the scenario calculations are constant marginal costs. The impact on the Baltic Sea is calculated assuming independence between measures.

Not all of the measures are used when analysing the costs and effects of different policy scenarios. Instead costs and effects are calculated for various combinations of measures. A scenario is constructed where a) the number of people connected to wastewater treatment is increased and the performance of the plants is improved in some countries, b) there is a 55 percent reduction in NO_x emissions from shipping and c) a reduction in agricultural land is undertaken. Calculations show that this scenario would reduce nitrogen loads by 106 kton and phosphorus loads by 13 ktons and that the total cost for this would be nearly 3 Billion EUR per year.

The study points out reductions of NO_x-emissions from shipping, catch crops, fertilizer reductions and a ban on phosphate detergents as particularly cost-effective measures. It is also argued that improvements in wastewater treatment coverage and technology can also be cost-effective in some locations.

Synthesizing data from all above studies: Gren (2008)

The recently published study by Gren (2008) builds on a cost-effectiveness model with basically the same structure and with the same methods for cost-estimation as in Gren, Elofsson and Jannke (1997). The Baltic Sea drainage basin is divided into 24 regions, and 14 measures for nitrogen and 7 for phosphorus reductions. Data from all above, as well as other, studies are included. Minimum costs for different levels of reductions in loads of nitrogen and phosphorus to coastal waters are calculated and the costs of e.g. a 50 % reduction in nitrogen loads is estimated to approximately 2800 Million EUR per year, while a proportional reduction in phosphorus would cost about 1800 Million EUR per year. Differences in results compared to e.g. Gren, Elofsson and Jannke (1997) can be explained by different baseline emissions as well as different measure coverage and data.

In addition to calculating costs for reductions to coastal waters, Gren (2008) investigates costs for reductions to different marine basins while assessing both the costs for reductions in loads to single marine basins as well as simultaneous reductions to all basins. Also, the cost and benefits are compared for three different policies: 1) marine basin targets according to the BSAP (HELCOM, 2007), 2) catchment-wise targets according to BSAP¹³ and 3) cost-effective reduction of total nitrogen and phosphorus loads to coastal waters where the total load reductions are equal to the total reductions suggested by BSAP. Here, the total cost for the first scenario amounts to 5.0 Billion EUR per year, for the second to 2.6 Billion EUR per year and for the third 1.7 Billion EUR per year. A comparison of the net benefits to different countries under these scenarios shows that Sweden, Finland and Germany are net winners under all target specifications and independently of the assumptions made about the discount rate¹⁴. Simultaneously, Poland, Latvia and Lithuania are losers under all these scenarios. Gren (2008) emphasizes the difficulties to calculate net benefits from nutrient reductions due to the limited information available regarding the benefits of such reductions (see also Hasselström and Söderqvist, 2008). In particular, comparisons of the net benefits under different targets are difficult because the scenarios results in different distributions of reductions over the different drainage basins, but the implications of this for the difference in benefits of the scenarios cannot be determined.

Gren (2008) also points out that there are properties of abatement measures that are not captured in a static cost-effectiveness model for the Baltic Sea, and presents an overview of the comparative advantages of measures with regard to the time delay between action and marine ecosystem response and the impact of measures on other environmental objectives than marine eutrophication. A comparison is also made regarding the robustness of different measures with respect to uncertainty about benefits and variations in costs and effects of measures throughout the Baltic Sea drainage basin. This comparison indicates that reductions in NOx-emissions from shipping and increased use of phosphate-free detergent give positive net benefits in the whole drainage basin and independently of assumptions regarding the discount rate. SCR-installation in power plants and trucks and investment in private sewers give negative net benefits under all assumptions and at all locations. This means that with assumptions made in the study, these measures are not economically motivated for the effect on the Baltic Sea only. However, if the measures affect also other environmental targets in positive way and this impact is large enough, then they can be economically motivated. For example, reductions in NOx.-emissions reduce acidification and improve human health, while private sewers may, if located upstream, improve local water quality. For all other measures the conclusions depend on the location of the measure as well as assumptions about the discount rate.

¹³ In this case, each country has a target for each catchment draining into a different basin.

¹⁴ The discount rate defines how future improvements of water quality and valued in comparison to improvements today.

Discussion about the Baltic-wide costs of nutrient reductions

Results from different studies should be compared with care, as geographical coverage, measures coverage, method and data may differ. One can note that with exception for COWI (2007), the parts of Belarus, Ukraine and the Czech Republic that fall within the borders of the Baltic Sea drainage basin are not included in either of the Baltic-wide models. Data for these countries are not easy to find and the HELCOM countries might be of larger interest due to their common international agreements. Still, good spatial and measure coverage is important if policy decisions are to be built on the results of cost-effectiveness studies.

Baseline emissions differ between models and are not always defined. Most of the studies present only costs for a single level of nutrient reduction. Gren, Elofsson and Jannke (1997) and Gren (2008) present costs for different reduction levels, wherefore the results in the other studies can be compared to these studies, see figure 3.

The number of measures covered matters to the outcome of the models. Only if the measures omitted are too expensive to be included in a cost-effective solution will the solution be unaffected. There are currently a relatively large number of measures included in the studies mentioned above. The difference in the number of measures between studies is still likely to affect results. Yet, there are measures not included in either of the models described, such as e.g. reduced tillage (cf. Ekman, 2005), removal or plugging of drainage from agricultural land (cf. Petrolia and Gowda, 2006), mussel cultivation (Hart, 2002) and measures to reduce emissions from households not connected to wastewater treatment plants.

All models, except Ollikainen and Honkatukia (2001) use constant marginal costs for a large number of measures. For this to be workable, it is necessary to also have assumptions about the capacity of each measure. Finding reasonable data on these capacities can be difficult at times; sometimes there are circumstances that set a natural limit to the use of a measure, sometimes the limits are less obvious. Even though assumptions about capacities are clearly stated in most studies, and the sensitivity to these assumptions can be analyzed, it is difficult to get a good picture about how different sets of capacity limits in different studies affect the outcomes.

Investment in wastewater treatment has been viewed as a major tool for reduced eutrophication in the international policy debate. The modeling of costs and capacities for reductions of nutrients from wastewater treatment plants is relatively rough in the Baltic wide models, e.g. most models except COWI (2007) assume there is only a single type of technology improvement. Differences in the current level of nutrient reductions in plants are treated in a rough manner. Results in COWI (2007) suggest that upgrading to different technologies can be relevant for phosphorus, but that upgrading to tertiary treatment is always less costly for nitrogen compared to other treatment technology levels. Investment in waste water treatment capacity in the countries south and east of the Baltic Sea is often suggested to be cost-effective

(see e.g. Kiirikki et al., 2003), but the relative merits of increased connection to wastewater treatment plants in relation to other measures have not been explored.

Nutrient transports are treated differently in the studies. In Gren, Elofsson and Jannke (1997), Elofsson (1999) and Gren (2008), the effect of measures is interdependent due to links between nutrient transports. In Ollikainen and Honkatukia (2001) retention of nutrients on the way from the sources to the sea seems not to be accounted for. The two remaining studies take nutrient transports into account but assume that the impact of one measure on coastal load is not affected by the scale of this measure or of the use of other measures. This assumptions leads to lower cost estimates compared to when measures are assumed to be interdependent. One can also note that data used on retention in different regions differ substantially between studies. The net impact of the differences in retention estimates on total costs cannot be determined for these studies.

Table 1. Comparison of models that calculate Baltic-wide costs of nutrient reductions to coastal waters.

	Gren, Elofsson and Jannke (1997)	Elofsson (1999)	Ollikainen and Honkatukia (2001)	Schou et al. (2006)	COWI (2007)	Gren (2008)
Number of measures included ¹	15	11	Measures included in HELCOM reports	10	16	14 for nitrogen and 7 for phosphorus
Sectors covered	Agriculture Wetlands Wastewater treatment Energy Transport	Agriculture	Measures included in HELCOM reports	Agriculture Wetlands Wastewater treatment Energy Transport	Agriculture Wetlands Wastewater treatment Phosphate free detergents Rural households Energy Transport	Agriculture Wetlands Wastewater treatment Phosphate free detergents Rural households Energy Transport
Nutrient transports from sources to the sea	Interdependencies between measures	Interdependencies between measures	Not included	No interdependencies	No interdependencies	Interdependencies between measures
Nitrogen target ² , reduction in total load to coastal waters	0-60 %	0-15 %	50 %	20 %	12 %	0-50 %
Phosphorus target ³ , reduction in total load to coastal waters	0-60 %	n.a.	50 %	n.a.	33 %	0-60 %

¹ A complete list of the measures can be found in the Appendix.

² Given that total N-loads to coastal waters are approximately 800,000 tons per year.

³ Given that total P-loads to coastal waters are approximately 37,000 tons per year.

In table 1, an overview is presented for the Baltic-wide models. As can be seen in this table, there are differences between the models concerning the measure and sector coverage, the treatment of nutrient transports and the coastal load reduction targets considered. The broadest measure and sector coverage can be found in Gren, Elofsson and Jannke (1997), COWI (2007) and Gren (2008). These studies differ however considerably with regard to the treatment of nutrient transports and the reduction targets considered.

Table 2. Comparison of results in Baltic-wide models.

	Gren, Elofsson and Jannke (1997)	Elofsson (1999)	Ollikainen and Honkatukia (2001)	Schou et al. (2006)	COWI (2007)	Gren (2008)
Nitrogen measures deemed cheap	Wetlands Agricultural measures Wastewater treatment	Fertilizer reductions Land use changes, Manure management	n.a.	NOx-reductions in energy sector Reduced fertilizer use Wetlands Catchcrops	NOx-red from shipping WWTPs in coastal urban areas Catchcrops, Reduced fertilizer use Manure-storage facilities	NOx-red from shipping Fertilizer reductions Wetlands
Nitrogen measures deemed expensive	n.a.	Livestock reductions	n.a.	Livestock reductions	NOx-red if only purpose is eutrophication target	NOx-red in energy and transport sector Private sewers
Phosphorus measures deemed cheap	Wastewater treatment, Wetlands Agriculture	n.a.	n.a.	n.a.	Wastewater treatment in coastal urban areas Phosphate-free detergents	Phosphate-free detergents Fertilizer reductions Wetlands
Phosphorus measures deemed expensive	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

As the studies include different measures and costs are estimated for different total load reductions, a comparison of the recommendations regarding low-cost measures must be made with this in mind. However, wetland construction, reductions in fertilizer use, improved manure management, catalytic cleaning of NOx from shipping and improved wastewater treatment is recommended in more than one study

to reduce nitrogen loads. For phosphorus, the importance of reductions at wastewater treatment plants and the use of phosphate-free detergents is emphasized in the studies including phosphorus, see table 2.

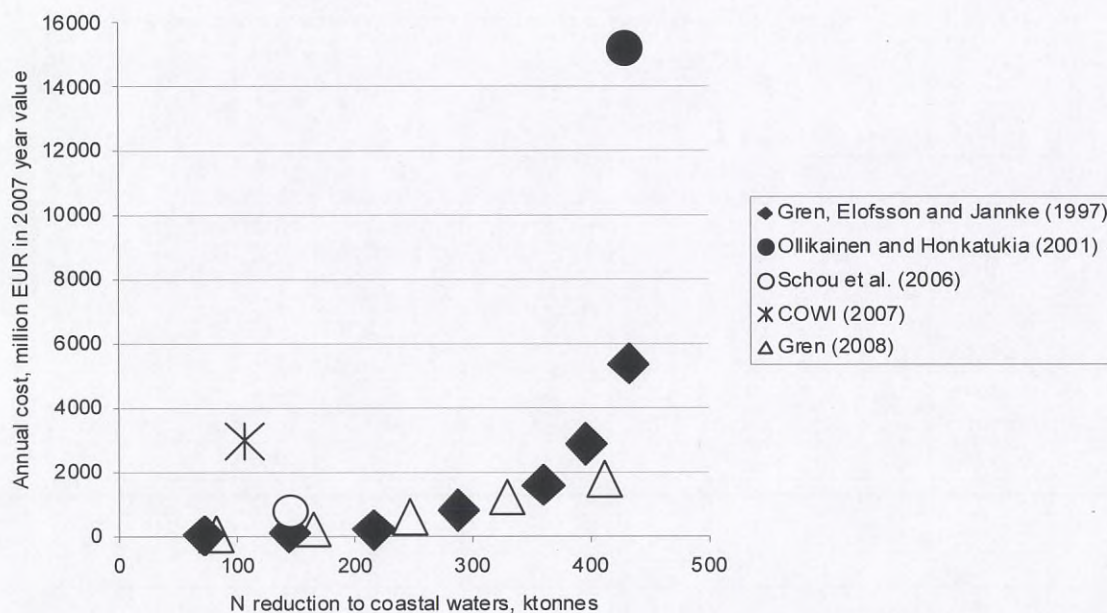


Figure 3. Minimum total cost for different nitrogen reductions in Baltic-wide models.

In figure 3, the total costs for nitrogen emission reductions are compared for four of the models. From the figure one can see that the costs for the combined policy analyzed in COWI (2007) are considerably higher than that in Gren, Elofsson and Jannke (1997). The most likely reason for this is that the scenario analyzed is not a cost-effective scenario, but the outcome of a limited set of more arbitrarily chosen policy measures. This illustrates the difference between cost-effectiveness analysis and analysis of the costs and effects of a policy program. Also the study by Schou et al. (2006) yields higher costs than Gren, Elofsson and Jannke (1997) for the comparable reduction level. The most likely reason for the difference is that the target in Schou et al. (2006) requires a fixed reduction for each marine basin. Also, more conservative assumptions about the capacity of different measures and differences in underlying data may explain the difference in total cost. The study by Ollikainen and Honkatukia (2001) gives much larger costs than Gren, Elofsson and Jannke (1997). The major reason is likely to be that costs are estimated based on a small subset of measures and this subset may not be representative for the larger supply of measures that can be available. Also, investments are assumed to have a short lifelength in Ollikainen and Honkatukia (2001) compared to the other studies. If retention had been taken into account in Ollikainen and Honkatukia (2001), costs in that study would have been even higher. The cost estimates in Gren (2008) are slightly lower than in Gren, Elofsson and Jannke (1997), which is counterintuitive

as reductions undertaken in the time between the two studies could have implied higher costs for reducing the remaining emissions. However, the difference may be explained by differences in measure coverage and data as well as reduced costs for some abatement technologies due to technological development.

Table 3. Losers under a cost-effective or cooperative solution (losers are marked with X).

	Nitrogen			Phosphorus		Nitrogen and phosphorus
	Gren, Elofsson and Jannke (1997)	Ollikainen and Honkatukia (2001)	Gren (2001)	Gren, Elofsson and Jannke (1997)	Ollikainen and Honkatukia (2001)	Gren (2008)
Sweden						
Denmark		X		X	X	
Germany				X		
Poland	X	X	X	X	X	X
Estonia	X		X			
Latvia	X	X	X	X		X
Lithuania	X	X	X	X	X	X
Russia	X		X	X	X	
Finland						

Of the studies discussed above, Gren, Elofsson and Jannke (1997) and Ollikainen and Honkatukia (2001) compare the incentives for countries to participate in a cost-effective international agreement on nutrient reductions. Gren (2008) presents net benefits for a couple of scenarios where both nitrogen and phosphorus are reduced. In addition to this, Gren (2001) analyzes the incentives for participation when both benefits and costs are taken into account and countries have the possibility to act as free-riders. The results from such comparisons are collected in table 3. The studies indicate strongly that Poland, Latvia and Lithuania as countries that may not prefer a cost-effective solution for nitrogen unless other countries contribute to the costs of abatement. For phosphorus, the two studies that present results on this both point out Denmark, Poland, Russia and Lithuania as countries that have smaller incentives for participating in an international agreement without additional compensation.

Skagerrak

There are no studies on the cost of reducing eutrophication covering Skagerrak's catchment, i.e. including the relevant parts of Sweden, Denmark and Norway (Franzén, Soutukorva and Söderqvist, 2006). Skagerrak has an exchange of nutrients with both Kattegat and the North Sea and thus, studies that cover these marine areas also have some relevance for Skagerrak. Using relatively rough assumptions about the costs of reducing nutrient loads from Skagerrak's own catchment, Franzén, Soutukorva and Söderqvist (2006) estimate that the total cost of reducing

loads to Skagerrak by 50 percent would be between 0.5 and 1.6 Billion EUR per year if measures in all Baltic Sea countries are assumed possible. If only emission reductions in Sweden and Denmark would be considered, costs would instead be 4-13 billion SEK per year, i.e. significantly higher.

In a Danish report regarding the costs of reductions of agricultural nutrient emissions, the costs associated with implementation of the Danish water management plan III (Jacobsen et al., 2004) are analyzed for a broad set of agricultural measures, although costs are not linked to the impact on different marine basins, and therefore conclusions for Skagerrak cannot be drawn.

Skagerrak is also connected to the North Sea, and estimations of costs to reduce nutrient loads to the North Sea are available in e.g. Nunneri et al. (2007), but the impact of the reductions for Skagerrak water quality cannot be derived from the study.

What factors determine the 'accuracy' of basin-wide cost-effectiveness studies?

Above, there is a discussion about how different factors within the studies reviewed affect the estimates of the minimum costs to reach eutrophication targets. Several factors not discussed above may affect the costs of reducing eutrophication, e.g.:

- implementation costs,
- changes in agricultural, fishery, energy, climate and inland water quality policies,
- positive and negative side-effects of nutrient policies in the Baltic Sea region,
- uncertainty and time dynamics and
- nitrogen and phosphorus interaction in the sea.

Firstly, one can note that there can be considerable differences between *ex ante* and *ex post* cost calculations. In an empirical study where 28 different regulations in the US are reviewed, Harrington, Morgenstern and Nelson (2000) show that generally, the difference is large between costs calculated before and observed after the implementation of a policy. They argue that per unit costs calculated in advance are likely to be inaccurate if technological innovation is not accounted for, cost information is out-of-date or underestimation of costs can be embarrassing for the persons responsible. Costs of a complete abatement program can be over- or underestimated for the same reasons, but insufficient information about compliance and aggregate baseline data may add to the problem. Low compliance will imply larger costs to reach a target, while incorrect aggregate baseline will lead to either higher or lower costs for target achievement, depending on the direction of bias in the aggregate baseline.

Secondly, policies in several fields affect both the needs for emission reductions and the relative costs of different abatement options. One of the most obvious cases

is agricultural policy. The Common Agricultural Policy in the EU countries has for many decades provided incentives for intensive agricultural production, which has contributed to larger emissions of nutrients. In 2003, the so called single farm-support was launched with an aim to reduce the negative impacts of agricultural support linked to production. The negative impacts targeted were both the overproduction of agricultural products and the negative environmental impacts from intensive production. The single-farm reform implied a decoupling of much of the agricultural support from production and this is expected to lead to lower nutrient emissions on the larger scale (see e.g. EU, 2007). For the smaller scale, the impact of agricultural reform on nutrient emissions may vary in both direction and magnitude between different catchments depending on the local production structure (see e.g. Lehtonen et al., 2007).

In recent years, some agricultural support has been shifted over to the rural development programs. For these programs, each country can decide on the extent and design of agri-environmental policy measures that address national environmental problems. In a study made before the 2003 reform, Brady (2003) concludes that for southern Sweden, agri-environmental policies directed towards nitrogen emissions barely compensates for the increase in emissions caused by production-related support. In addition to this, he shows that the cost-effective strategy differs with and without production-related support. The reason for this is that the relative profitability of different agricultural activities is different with and without production-related support. As further decoupling reforms can be expected in the next decades, this may thus have significance for nutrient policies. In this context, one can also note that the recently increased agricultural world market prices (see e.g. OECD-FAO, 2007) will, if stabilized, counteract the effect of agricultural decoupling reforms as the higher prices provide incentive for more intensive agricultural production.

Eutrophication of the Baltic Sea is also linked to eutrophication problems in inland waters and high nitrate levels in groundwater. These inland water quality problems differ from the internationally common water quality problems of the Baltic Sea because the former can be solved on national basis, while the latter cannot. Joint economic analysis of inland and high-sea eutrophication is not available for the Baltic Sea region or Skagerrak. As the solutions to these problems lie in one case on national or regional governments and in the other on international cooperation between different government, which is known to be more complicated, it would be valuable to be able to make a distinction between the regional/national problem and the international problem, respectively.

Climate change and climate policy are both likely to affect cost-effective abatement strategies for the Baltic Sea. Climate change is expected to increase the riverine outflow of nutrients to the Baltic Sea (Arheimer et al. 2005) and thereby increase the need for nutrient reductions. A global temperature increase could, at least in the short run, imply a comparative advantage for farming in the Baltic re-

gion compared to countries further south and this might contribute to larger emissions. As a response to climate change, policies against the greenhouse effect can be expected to become more stringent. Several studies show that climate policies directed towards CO₂-emissions will, as a side-effect, also lead to reduced NO_x-emissions (see e.g. Östblom, 2007; Östblom and Hammar, 2007). On the other hand, increased intensive cultivation of energy crops on arable land due to heavier taxation of fossil fuels or subsidies to energy crops might lead to increased nutrient emissions depending on the crop chosen. Thus, there might be a direct impact of climate change on both agriculture and eutrophication, and an indirect impact due to the responses of policy makers and farmers (see e.g. Abler et al., 2002).

Recent research has shown that nutrient concentrations may depend on the stock of different fish in the Baltic Sea (see e.g. Hjerne and Hansson, 2002). Thus, there are potentially important links between economics, eutrophication and fishery policy (cf. e.g. Knowler, Barbier and Strand, 2001), but the implications of these links have not yet been explored from an economic viewpoint for the Baltic Sea.

There can be side-effects of nutrient reduction policies, e.g. if NO_x-emissions are reduced with a purpose to reduce nutrient loads to the Baltic Sea. NO_x reductions can lead to improved air quality and thereby enhanced health. The benefits from NO_x reductions are estimated to be high when NO_x is considered a proxy for the general level of air pollution (Samakovlis et al., 2005). Krupnick et al. (1998) provide a framework for analysis of the costs of NO_x-reductions, the impact on nutrient loads and the benefits of reduced ozone exposure in an application to the Chesapeake Bay, which is the largest estuary in the United States and severely affected by eutrophication. Negative side-effects are also possible: wetland creation can affect the emissions of greenhouse gases such as methane and nitrous oxides (Schou et al., 2006). Studies investigating these side-effects on a larger scale are not available for the seas surrounding Sweden. Positive side-effects on marine eutrophication policies would imply that the costs that can be attributed to the achievement of marine eutrophication targets would be lower, while the opposite holds for negative side-effects.

Ecosystem behavior and assumptions in this regard are important to the analysis of cost-effective strategies. Uncertainty is an unavoidable component in analysis of policies for large-scale ecosystems. So far, the role of uncertainty for the costs of nutrient policies for the Baltic Sea has only been analyzed to limited extent (e.g. Elofsson, 2003). Small-scale studies show that the links between different types of uncertainty can be of importance for the cost-effective policy choice (see e.g. Byström, Andersson and Gren, 2000). However, uncertainty can have more far-reaching implications than shown by these studies, e.g. regarding the timing of different actions and the need for learning, experiments and research.

So far, no Baltic-wide models have been developed to take the role of time dynamics into account. Taking time lags into account means that the distribution of

abatement over time can be analyzed, including the timing of investments and the adjustment of the Baltic Sea ecosystem to a new equilibrium. On small scale, Hart (2003) investigates mussel cultivation on the Swedish west coast as one option in a cost-effective abatement program, using a complex model of ground- and surface water transports and concludes that in the presence of time lags, it can be optimal to apply downstream measures like mussels more intensively in an earlier phase of the abatement in order to achieve the environmental target at lowest possible cost. Laukkanen and Huhtala (2008) develop a model for the Finnish coastal waters of the Gulf of Finland, where the links between investment in wastewater treatment facilities and the time dynamics of ecosystem response are analyzed. Results show that in the baseline solution, immediate investment in St. Petersburg's wastewater facilities is cost-effective, although the conclusion is sensitive to assumptions made about ecosystem behavior. Yet no dynamic model is available to analyze the links between economic activity and Baltic-wide ecosystem response.

The recent debate about the roles of nitrogen and phosphorus, respectively, for eutrophication suggests that it could be important to take nutrient interdependence into account when making economic analysis. Analysis in Elofsson (2003) shows that assumptions regarding the links between nitrogen to phosphorus with regard to environmental damage is important to the cost-effective strategy and that it is highly unlikely that proportional reductions of both nutrients, such as was required by the earlier HELCOM targets, are cost-effective. The reason is that if environmental damage depends jointly on both nutrients it is necessary to consider both the impact that nutrients have on damage and the costs for load reductions, when the relative reductions in the two nutrients is decided upon. So far, models of environmental damage that permit realistic empirical analysis of these issues are not available.

Research needs

In view of the multiple factors that affect the costs of remediating eutrophication of the Baltic Sea one conclusion must be that there will never be a model that captures all important aspects of the problem. Instead, policies need to build on robust results, i.e. on results that are valid even under many different assumptions and circumstances. These robust results can be derived either through comparison of the outcomes of a larger set of studies or from analysis of robustness in studies where appropriate methodologies are used for this specific purpose.

This study is limited to the analysis of costs, and recommendations regarding further research should therefore be made within the field reviewed. Research needs are, as just mentioned, analysis of the robustness of results in cost-effectiveness studies but also research on the role of agricultural policies and markets for the need for and costs of nutrient reductions on Baltic-wide scale. As shown in small-scale studies, agricultural policy will affect both the overall nutrient emissions and the relative costs of different abatement options, and changes in the mar-

kets for agricultural products can have the same effect. The role of climate change and climate policies for cost-effective abatement strategies is yet another field which researchers have not yet to any larger extent addressed from an economic perspective. In addition, the cost for implementation of policies is another area, which is not covered in this review but yet is highly important for the outcome of policy programs. A first step could be to make a comprehensible review over studies made regarding implementation costs and policy instruments.

As becomes clear from this review, ecosystem response is highly important to the cost-effective allocation of measures, and further research in this field is therefore valuable, in particular with a purpose to analyze robust abatement strategies.

Hazardous substances

A hazardous substance is a mixture of elements or compounds either naturally occurring or produced synthetically. Such substances can be toxic to people and ecosystems. Within HELCOM, substances are defined as hazardous if they are toxic, persistent and bio-accumulative (PBT-substances), or very persistent and very bio-accumulative (vPvB). Moreover, substances which affect hormonal and immune systems are also considered hazardous substances and are deemed to be of equal concern (HELCOM, 2007b).

Once released into the sea, hazardous substances can remain in the marine environment for very long periods and can accumulate in the marine food web up to levels which are toxic to marine organism. Hazardous substances cause adverse effects on the ecosystem, such as

- impaired general health status of animals,
- impaired reproduction of animals, especially top predators and
- increased pollutant levels in fish for human consumption.

Levels of some hazardous substances in the Baltic Sea exceed concentrations in e.g. the North East Atlantic by more than 20 times (HELCOM, 2007b). Certain fish species caught in some parts of the Baltic Sea are not suitable for human consumption as they contain concentrations of hazardous substances exceeding requirement levels. Although monitoring indicates that the loads of some hazardous substances to the Baltic Sea have fallen over the past 20–30 years, problems still persist; and concentrations in the marine environment of some new substances have even increased (HELCOM, 2007b).

For the Baltic Sea, HELCOM expresses the strategic goal as a “Baltic Sea life undisturbed by hazardous substances” (HELCOM, 2007b). This is interpreted in more concrete terms as reaching concentrations of hazardous substance close to natural levels, having all fish safe to eat, having healthy wildlife and reaching pre-Chernobyl levels of radioactivity. According to HELCOM (2007b), the short term target is a decreasing trend in concentrations for all substances, while the medium term target is to reach EU maximum levels in muscle meat of fish for mercury, cadmium, dioxins, furans and dioxin-like PCBs. The long-term target level is to reach near background concentrations for naturally occurring substances (mercury, cadmium, dioxins, furans and dioxin-like PCBs) and to reach close to zero concentrations for man-made synthetic substances (TBT and PFOS). The substances claimed by HELCOM (2007b) to be of specific concern to the Baltic Sea are shown in table 4.

The information needed to calculate cost-effective solutions for reductions in hazardous chemicals are in principle the same as described above in this chapter: there has to be a well-defined target as well as information about the costs for the relevant measures and the impact of those on the target. The latter implies that it is necessary to have information not only on transport pathways but also on persistence, decay and bioaccumulation. Without this information, preventive and remedial measures cannot be compared with regard to the impact on the targets. In addition to this, it is necessary to have information on e.g. regional and domestic production of hazardous substances as well as on use and trade. Such information is generally insufficient and the same applies to data on release, disposal and storage of hazardous substances (Selin and VanDeveer, 2004).

Table 4. Substances of specific concern to the Baltic Sea

<i>Organic substances</i>
1. Dioxins (PCDD), furans (PCDF) and dioxin-like PCBs
2a. Tributyltin compounds (TBT)
2b. Triphenyltin compounds (TPhT)
3a. Pentabromodiphenyl ether (pentaBDE)
3b. Octabromodiphenyl ether (octaBDE)
3c. Decabromodiphenyl ether (decaBDE)
4a. Perfluorooctane sulfonate (PFOS)
4b. Perfluorooctanoic acid (PFOA)
5. Hexabromocyclododecane (HBCDD)
6a. Nonylphenols (NP)
6b. Nonylphenol ethoxylates (NPE)
7a. Octylphenols (OP)
7b. Octylphenol ethoxylates (OPE)
8a. Short-chain chlorinated paraffins (SCCP or C10-13)
8b. Medium-chain chlorinated paraffins (MCCP or C14-17)
9. Endosulfan
<i>Heavy metals</i>
10. Mercury (Hg)
11. Cadmium (Cd)

Source: HELCOM (2007b).

The set of substances that are of interest here is relatively large, and when it comes to remedial measures such as e.g. removal of contaminated sediments, there are likely to be joint costs of abatement because many different substances can be removed at the same time. Therefore, it can be relevant to make joint analyses for multiple substances. If the target is one of reducing the overall effects of hazardous substances, then it is necessary to weigh the impact of different substances against each other. When it comes to policies for contaminated sites on land, these can be classified according to risk (cf. Forslund, Samakovlis and Johansson, 2006). Such risk comparisons could also be adequate for weighting the environmental risk associated with different contaminated sediment sites or for weighting different hazardous compounds against each other. Such weighting is necessary if the benefits of

environmental clean-up operations should be compared, or if the target is to reduce the overall risks associated with different sites.

Systematic investigations of costs of reducing the levels of hazardous substances in the Baltic Sea or Skagerrak are not available. Yet there are studies regarding e.g. treatment of contaminated sediments, abatement of heavy metals and the costs of a ban on TBT (tributyltin) that might serve as a point of departure for future work in this field. In a study concerned with remedies to sediment contamination in e.g. Kristiansand Fjord¹⁵, Laugesen et al. (2001) calculate the costs for treatment of contaminated sediments and compare a number of different techniques with regard to the costs per cubic meter sediment. They note also that different measures are likely to be more or less adequate depending on the local circumstances, such as the type of contaminants present, sediment thickness and volume, sediment type, distance from the site to the coast, water depth and topography.

For some types of substances, such as e.g. mercury, there is literature, from which information about the costs for reductions at the different sources can be compiled. Hylander and Goodsite (2006) review and calculate costs for both preventive and remedial measures against mercury pollution for a broad set of measures. According to their compilation, measures such as collecting metallic mercury and mercury compounds from school labs, recycling of chairside traps in dentistry and removal of amalgam fillings at death could be measures with lower costs than average. Vandeven and McGinnis (2004) review in detail cost-effective ways of removing amalgam, which contains mercury, from dental wastewater in California, while Cerreño, Panero and Boehme (2002) analyze costs as well as technological and administrative feasibility of mercury abatement for multiple sectors around the New York/New Jersey Harbour. Extensive data on costs at the sources for reductions of mercury emissions to air are reviewed by the EU (2001). Similar studies of the costs of cadmium emission reductions at the sources can also be found (see e.g. Peirce et al., 2002). None of the above studies on heavy metals take into account pollutant transports, decay, release or bioaccumulation. Analyzing the role of pollutant transports for the cost-effective abatement strategies against heavy metals in the river Dalälven catchment in Sweden, Baresel, Destouni and Gren (2006) conclude that down-stream measures such as wetland are cost-effective if there is uncertainty about the distribution of emissions on different sources of origin. The intuition behind this result is that if one uses the same money, that is spent on wetlands on the sources instead, then some of this money will be wasted if the source does not give rise to emissions.

Tributyltin (TBT) is one of the hazardous substances targeted by HELCOM. It is used on ship hulls as an anti-fouling agent. TBT is mainly spread via international maritime transports, although the substance is also used in wood preservatives and can be found in e.g. clothes. It is persistent and bioaccumulating, and reduces im-

¹⁵ Kristiansand Fjord is located on the Norwegian Skagerrak coastline.

mune defense systems and changes the hormone balance. For vessels under 25 meters IMO (the International Maritime Organization) has banned the use of TBT, but larger vessels may still sail in spite of being painted with TBT.

In an analysis of the costs and benefits of a TBT ban, Abbott et al. (2000) argue that the costs of a ban due to lower speed when the hull is fouled are large because of delays and increased use of fossil fuels. As a consequence of the larger fossil fuel use, emissions of CO₂ and sulphur might increase. Champ (2000) notes that the TBT ban increases the risk of introduction of invasive species that might foul the hulls and so get transported between different seas and argues that this has not been fully accounted for when evaluating the costs and benefits of the new restrictions on TBT-use on smaller vessels. Abbott et al. (2000) note that current legislation aims only at a prevention of further contamination but provides no guidance on the abatement of TBT already accumulated in the eco-system.

The role of time dynamics and the persistent nature of hazardous substances are rarely analyzed in applied economic studies, most likely due to the difficulties to obtain appropriate data. One exception to this is Conrad and Olson (1992) who analyze strategies for reductions in the concentrations of a pesticide outside eastern Long Island. In this study, the time dynamics used in the economic model are estimated by the authors themselves based on time series data on agricultural use of the substance and concentrations in the water. Results from the study show when and how much to abate in order to achieve a future environmental target.

For other hazardous substances targeted by HELCOM, studies that investigate cost-effective strategies have not been found. The findings in this section show that existing cost analyses of measures aiming at reductions in hazardous substances almost exclusively deal with the costs of emissions reductions at the sources. If the target is to reduce concentrations of those substances in the sea water, sediments, fish and other animals, this approach is not sufficient even if one would judge that cost estimates would be applicable for the Baltic Sea and Skagerrak regions. As a consequence, preventive and remedial measures are not compared in a consistent manner in the existing studies. Instead cost calculations are based on the implicit assumption that reducing emissions by 1 kilo at the sources would have the same impact as e.g. removing 1 kilo from sea sediments. This is not likely to hold and moreover, neither is likely to imply a 1 kilo reduction of the substance in sea water. In addition, there may be situations where it is better to leave contaminants in the sediments due to the risk of dispersal when removing sediments. Finally, the role of time lags associated with release and accumulation of hazardous substances is little analyzed in the applied economic literature.

Research needs

For hazardous substance, there is basically no economic research done applied to the Baltic Sea and the Skagerrak. Thus, there is a need to link economic activities

and the costs for changes in these activities to environmental targets, as well as a need to compare different abatement options with regard to the costs and the effects on water quality. This type of work might only be possible at a smaller scale to start.

Maritime activities

The Baltic Sea is one of the most intensely trafficked marine areas in the world. Both the numbers and the sizes of ships have been growing in recent years, especially oil tankers, and this trend is expected to continue (HELCOM, 2007a). This heavy traffic occurs in narrow straits and shallow waters that are covered by ice for prolonged periods in winter, making the Baltic Sea a difficult area for navigation, with an increased risk of shipping incidents. The main environmental effects of shipping and other activities at sea include pollution to the air, illegal and accidental discharge of oil, hazardous substances and other wastes, and the introduction of invasive alien organisms via ships' ballast water or on their hulls. Oil spilled deliberately or during accidents may destroy important marine and coastal habitats, and alien species may cause economic loss and even pose risks to human health (HELCOM, 2007a). The risk of oil spills is considerable also for Skagerrak. Huge amounts of heavy crude oil are transported through the Skagerrak from ports in Russia and the Baltic countries. Franzén, Soutukorva and Söderqvist (2006) argue that the cleanup costs from a major oil spill in the Skagerrak could be large, in particular if shorelines are affected. In the following, studies regarding the costs of reducing oil spills are examined.

Oil spills

Under the target of environmentally friendly maritime activities reductions in oil spills, accidental and deliberate, is one of the concrete aims. Increasing amounts of oil are transported through the Baltic Sea and in 2005 more than 210 million tonnes were transported via the largest oil terminals in the Baltic Sea (HELCOM, 2007a). Surveillance efforts have been strengthened with regard to the number of flight hours since the end of the 1980's, while the number of illegal discharges detected has fallen. There is not a clear trend with regard to the quantity of oil illegally discharged and detected.

The damage from oil spills can be reduced through reductions in the probability of an oil spill or through oil spill clean ups after a spill has occurred. The probability of an accidental oil spill due to collisions and grounding can be reduced through broadening or deepening of transportation lanes while the incentives for deliberate oil spills might be reduced through enhanced control efforts. Once an oil spill has occurred, the cleanup is almost never complete. Thus, it is necessary to take into account also the environmental damage that can result also after a cleanup operation. Changes in the localisation of transportation lanes might reduce environmental damages from oil spills independently of whether it is detected or not.

The probability of an oil spill depends on the underlying determinants of risk such as e.g. the amount of shipping, the amounts of oil transported, enforcement efforts and requirements for assisted navigation. These underlying determinants are often factors that can be influenced by policy decisions. The resulting probability de-

depends on a number of factors and Bigano and Sheehan (2006) show through a bottom-up approach how oil spill probabilities can be calculated based on information about the probability of different events that contribute to the risk of an accident. Having calculated the risk of oil spill due to grounding or collision on some vulnerable sites in the Mediterranean, they show how the resulting probabilities can be used together with data on clean-up costs to calculate the expected clean-up costs for differently large oil spills at the chosen locations.

A number of technological factors affect the costs of oil spill cleanups, such as the type of oils spilled, the method used, the size of the spill, the location and the extent of shoreline pollution (Etkin, 2000). Based on actual cleanups, Etkin (2000) reports on average per-unit costs in 1999 of oil spill cleanups for a large number of the world's countries. According to these calculations, the average cost for the countries adjacent to the Baltic Sea and Skagerrak ranges between 60 EUR per ton for Lithuania to 15,900 EUR per ton in Norway. In addition to this, the relation between average cost and different technical and physical factors are analysed. The total costs of oil spill cleanups are likely to depend on enforcement, and Epple and Visscher (1984) show that the number of oil spills detected may actually increase with increased surveillance, because the increase in the number of detections may outweigh the decrease the number of oil spills.

Acknowledging the role of enforcement for oil spill abatement costs, Cohen (1986) analyses the costs of oil spill cleanup from oil-carrying vessels based on data from the US Coastguard. For these vessels, oil spills typically occur either during an oil transfer operation or is the results of a major casualty. He notes that the vessel-owner has considerable economic incentives to avoid oil spills due to accidents apart from the potential cost of the cleanup operation. In the case of a casualty, there can be considerable costs associated with damages to the ship, losses of revenue because the ship must be repaired or cannot be used for a longer time and costs for crew hurt or left without work. Thus one might conclude that the private cost of oil spills can be an important determinant of the risk of an accidental oil spill. This means that there are smaller private incentives to avoid accidents if a vessel and its cargo has low private economic value. In addition to this, the probability of an oil spill may depend on design and status of the ship as well as enforcement of regulations on oil spills. Cohen (1986) estimates first how the extent of oil spills depends on enforcement efforts. Secondly, the role of the amount and fraction of oil recovered, the type of oil and the party responsible for the cleanup operation¹⁶ for total oil spill cleanup costs is analysed. Results show that the amount of oil cleaned matters for the costs but that the role of the fraction cleaned is unclear. Polluter cleanups tend to be more costly than governmental cleanups, and the author suggests that one reason for this is that polluters might tend to overestimate cleanup costs in order to convince the government that cleanups are too costly. Based on the above mentioned calculations, Cohen (1986) estimates how expected total oil

¹⁶ Either the polluter or the government could be responsible.

cleanup costs changes with different levels of enforcement efforts. In addition to this, Cohen (1987) shows that different types of enforcement efforts, such as actual monitoring of oil transfer operations, random port patrolling and vessel inspection, have a different impact on the amounts of oil spilled. Results showed that the two first methods had a larger deterring impact than the third. He then concludes that it is likely that a better effect can be achieved by reallocating enforcement resources in a suitable way, even with a fixed enforcement budget.

Improved transport lanes and enhanced surveillance can be more costly in Skagerrak than cleaning up an oil spill once it has occurred (Franzén, Soutukorva and Söderqvist, 2006). However, this is not sufficient for concluding that preventive measures should not be undertaken, as there are additional damages from oil spills after the cleanup, because not all oil can be recovered. The oil that remains in the sea can cause damage on fishery, biodiversity, aquaculture and tourism.

Analysis of the oil spill cleanup costs or costs for preventive measures that reduce the probability of an oil spill are not available for the Baltic Sea. An analysis of the costs of oil spill cleanups and preventive measures that reduce the probability of spills in the Baltic Sea and Skagerrak would require analysis of the probabilities of oil spills and how they change with adjustments in e.g. enforcement activity or the design of transportation routes. In addition to this, the costs for oil spill cleanups in the Baltic Sea and Skagerrak would require a deeper analysis with regard to the determinants of these costs, to get a better understanding of how costs depend on technology, oil spill prevention policy and other factors. An economically optimal strategy would require an integration of these issues into a consistent framework, where both preventive and remedial measures are analyzed together with the damage costs of oil spills.

Alien species

Introduction of non-native species is a threat to the Baltic biodiversity which is difficult to manage by the available methodology (HELCOM, 2007a). Ballast water treatment is one option to reduce the influx of alien species. The Ballast Water Management Convention foresees two management options aiming at reducing the risk of alien species introduction: ballast water exchange and a stepwise application of onboard ballast water treatment systems, enabling achievement of reduced numbers of organisms per ballast water volume unit (HELCOM, 2007a). Estimates of the costs of ballast water treatment systems can be found (e.g. Wallenius Lines, 2006), but indications of the impact on sea biodiversity cannot be determined and thus this action cannot be compared to alternative actions to improve or protect sea biodiversity. As mentioned above, the use of TBT on hulls is another way to reduce the inflow of alien species, although with negative side-effects due to the release of toxic substances. Also in this case, it is not possible to say how large the impact on biodiversity would be from permitting or banning the use of TBT. At this point, the lack of measurability regarding the effect on biodiversity seems to be a consider-

able obstacle for cost-effectiveness comparisons regarding different measures aiming a strengthening and protecting sea biodiversity.

Research needs

For maritime activities, both research that provides a framework for comparison of costs and effects of different types of actions as well as research that explores the costs and effects of particular measures can lead to further insights with regard to the cost-effectiveness of different policy strategies. Both for oil spills and alien species-introduction, the use of probabilistic frameworks seem to be motivated. In particular for oils spills, it seems likely that useful results can be obtained in a relatively near future.

Conclusions

Large environmental improvements cannot be reached without costs to society. Recognition of cost-effective strategies is fundamental for decisions makers who want to:

- reach environmental targets without wasting society's resources on unnecessarily expensive abatement programs,
- obtain the maximum environmental impact from a given budget or
- find out whether the net benefits of a planned policy or project are positive.

In this paper, the costs of improved environmental conditions in the Baltic Sea and the Skagerrak are discussed. Of particular interest for decision makers that care about costs is the relationship between the costs and effects of a measure or a policy strategy. When costs can be compared to the impact on a pre-specified environmental target, one can draw conclusions about the cost-effective strategy. When costs can be compared to the benefits that are associated with the resulting environmental improvement, it is possible to determine the net benefits of a strategy.

Three steps are necessary in order to define a cost effective allocation of measures. The first is to interpret the politically determined environmental target into a measurable target indicator if the politically determined target is broadly defined. The second is to calculate costs of measures at the sources and the third to quantify the impact of measures on the target. Information about the impact of measures, undertaken as a consequence of the introduction of policy instruments and legislation, on environmental target for the sea is often not easy to find. One reason is that in existing studies, based on natural science, impacts do often not relate to measures that can be directly effected for policies and for which costs can be calculated. Also, there is frequently limited scientific knowledge about the impacts, the qualitative impact may be known, i.e. one may know whether the impact is positive or negative, but it may not be possible to measure how large the impact is.

A number of human activities affect the sea environment and provision of ecosystem services of the seas. Some of these human activities are e.g. excessive nutrient loads, emissions of hazardous substances, unsustainable fishery regimes, shipping, building and construction and greenhouse gas emissions (Garpe, 2008). Changes in these activities toward more environment friendly practices give rise to costs. This literature review explores the state-of-the-art of studies analyzing the cost of environmental improvements in the Baltic Sea and Skagerrak. In this report, studies that are related to reductions in nutrients and hazardous substances, oil spill abatement and alien species introduction are discussed. Studies concerning greenhouse gas emissions are excluded because of the global nature of the problem which requires that the problem is analyzed on global scale rather than regional. Economic analysis of building and construction activity usually refers to individual projects, and the aggregate role of this type of activity for sea ecosystems is difficult to determine.

Eutrophication

A number of studies on costs of reducing nutrient loads have been published in the last 15 years. Of those a handful analyze cost-effectiveness on a Baltic-wide scale. A comparison of these Baltic-wide studies shows that all studies but one ignore the parts of Belarus, Ukraine and the Czech Republic that fall within the borders of the Baltic Sea drainage basin. There can be a variety of reasons for this exclusion: data for these countries may not be easy to access and the HELCOM countries might be of larger interest due to their common international agreements. Still, good spatial coverage is important if policy decisions are to be built on the results. The comparison also shows that there are differences in the number of measures covered. This can be important for the results if low-cost measures are excluded. Yet, several possible measures are not included in either of the models described, such as e.g. reduced tillage, removal of drainage, controlled drainage, mussel cultivation and increased connection to sewage treatment. It is worth noting that there is no natural scientific model covering the Baltic Sea drainage basin, from which the impact on the sea of different measures can be derived. Hence, all the models use data on the impact compiled from a large number of sources, different to all studies. Most Baltic-wide studies assume that the impact of a measure on nutrient loads is independent of the use of other measures and the scale of abatement. There are variations between studies regarding the estimates of the costs of Baltic-wide nutrient reductions. Lower costs are in most cases likely to be explained by a combination of broad measure coverage and a general target formulation. Differences in assumptions about the capacity of different abatement measures and differences in data may also affect the results. The comparison also highlights the difference between cost-effectiveness analysis and analysis of the costs and effects of a policy scenario defined on e.g. political grounds, where the latter will always result in higher costs unless the policy scenario coincides with the cost-effective solution.

The results from the studies cannot in a reasonable way be used to calculate the expected cost for achievement of neither the old nor the new HELCOM targets, because only two studies address the old target while covering abatement options in all sectors and only one study covers the new HELCOM targets. However, the most recent study estimates the minimum costs of a 50 % reduction in nitrogen loads, which is equal to the earlier target set by HELCOM, to approximately 2760 Million EUR per year. This latest study makes use of data from most earlier studies. The same study compares the cost and benefits for three different scenarios based on the new HELCOM targets, which are expressed as both marine basin targets and country-wise targets. The scenarios analyzed are: 1) marine basin targets according to the BSAP, 2) multiple catchment targets for each country according to BSAP and 3) cost-effective reductions of total nitrogen and phosphorus loads to coastal waters, where the total load reductions are equal to the total reductions in the BSAP targets in scenario 1 and 2. Here, the total cost for the first scenario amounts to 5.0 Billion EUR per year, for the second to 2.6 Billion EUR per year and for the third 1.7 Billion EUR per year.

The results in the studies suggests that wetland restoration, reductions in fertilizer use, improved manure management and improved wastewater treatment are low-cost measures for nitrogen. For phosphorus, reductions at wastewater treatment plants are emphasized in the studies, complemented by wetlands and phosphate-free detergents.

Some Baltic-wide studies compare the incentives for countries to participate in a cost-effective or optimal international agreement on nutrient reductions. These studies point out Poland, Latvia and Lithuania as countries that may not prefer a cost-effective or cooperative solution unless other countries compensate them. Sweden and Finland seem to be the main winners from Baltic-wide nutrient reductions when no compensations are made between countries.

The 'accuracy' of cost estimates in Baltic-wide models with regard to the costs that may arise if a cost-effective policy is actually implemented can be challenged as technological innovation and implementation costs are not accounted for. The role of uncertainty and time lags for the minimum cost is little analyzed, and results from small-scale studies suggest that there is a need to further address these issues on Baltic-wide scale. Moreover, changes in agricultural, energy, climate and inland water quality policies can play an important role for the cost-effective abatement strategy, as well as for the future need to reduce loads to the sea, wherefore further research in these areas seems necessary. The reason that agricultural and energy policies affect the cost-effective strategies is the impact that these policies have on the relative costs of different abatement options. The existence of synergies with other environmental goals, such as for climate and inland water quality, implies that measures that are not motivated in a cost-effective strategy for the sea only, might be motivated if their joint impact on different targets is accounted for.

In view of the multiple factors that affect the costs of remediating eutrophication of the Baltic Sea, one conclusion must be that there will never be a model that captures all important aspects of the problem. Instead, policies need to build on robust results. These robust results can be derived either through comparison of the outcomes of a larger set of studies or from analysis of robustness in studies where appropriate methodologies are used for this specific purpose.

This study is limited to the analysis of costs. Within this field there is a need for further analysis of the robustness of results in cost-effectiveness studies, i.e. results that are stable with regard to assumptions and modeling approach. In particular, the role of agricultural policies and markets for the need for and costs of nutrient reductions on Baltic-wide scale are of interest. Also, the role of climate change and climate policies for cost-effective abatement strategies is a field which researchers have not yet to any larger extent addressed from an economic perspective. In addition, the cost for implementation of policies is another area, which is not covered in this review although it is highly important for the outcome of policy programs.

Implementation of policies at international, national and regional level need to be further analyzed with regard to incentives for participation and policy instruments that support cost-effectiveness in the presence of uncertainty. A first step could be to make a comprehensible review over studies made regarding implementation costs and policy instruments. As is clearly shown by this review, ecosystem response is highly important to the cost-effective allocation of measures, and further research in this field is therefore valuable, in particular with a purpose to analyze robust abatement strategies. Other issues, which can be investigated further are e.g. capacity limits for different measures, where in principle, there can be different ways to approach these limits, as they can be defined either based on technological or economic criteria.

Hazardous substances

The information needed to calculate cost-effective solutions for reductions in hazardous chemicals is similar to that described above: there has to be a well-defined target as well as information about the costs for the relevant measures and the impact of those on the target. For hazardous substances, this implies that it is necessary to have information not only on transport pathways but also on persistence, decay and bioaccumulation. This information must be possible to link to economic models. Without such information, preventive and remedial measures cannot be compared with regard to the impact on the targets. In addition, it is necessary to have information on e.g. regional and domestic production and use of these substances. Such information is not always available and the same applies to data on release, disposal and storage of these substances.

Systematic investigations of costs for reducing the levels of hazardous substances in the Baltic Sea or Skagerrak are not available. Yet there are studies regarding the costs of e.g. treatment of contaminated sediments, abatement of heavy metals and a ban on TBT (tributyltin) that might serve as a point of departure for future work in this field. Studies on costs of heavy metals abatement, applied to other parts of the world do, however, with few exceptions ignore pollutant transports, decay, release and bioaccumulation. For TBT, a couple of studies sketch the costs and benefits of a ban, while discussing also the role of TBT for the risk of alien species introduction.

As there is basically no economic research done applied to the Baltic Sea and the Skagerrak, there is a need to undertake research that links economic activities and the costs for changes in these activities to environmental targets, such that different abatement options can be compared with regard to the costs and the effects on water quality. This type of work might only be possible at a smaller scale to start.

Maritime activities

Reductions in oil spills, accidental and deliberate, is one of the environmental objectives of HELCOM. The damage from oil spills can be reduced through reductions in the probability of an oil spill or through oil spill clean ups after a spill has

occurred. Some ways to reduce the probability of an oil spill is to broaden or deepen transportation routes to reduce the probability of collisions and grounding or to enhance control efforts to reduce the incentives for deliberate oil spills and the risk for oil spills due to negligence. Changes in the localization of transportation routes might reduce environmental damages from oil spills. Once an oil spill has occurred, the cleanup is almost never complete. Thus, when considering ex-post cleanups as an abatement option it is necessary to take into account also the environmental damage that may occur even after a cleanup operation.

Introduction of non-native species is a threat to the Baltic biodiversity which is difficult to manage by the available methodology. Ballast water exchange and a stepwise application of onboard ballast water treatment systems can, however, reduce the numbers of organisms per ballast water volume unit. Estimates of the costs of ballast water treatment systems can be found, but the effect of this action cannot be compared to alternative actions to improve or protect sea biodiversity. The difficulty to quantify the impact of measures is likely to be a considerable obstacle for cost-effectiveness comparisons regarding the objective to strengthen and protect sea biodiversity.

For maritime activities, both research that provides a framework for comparison of costs and effects of different types of actions as well as research that explores the costs and effects of certain measures can lead to further insights with regard to the cost-effectiveness of different policy strategies. Both for oil spills and alien species introduction, the use of probabilistic frameworks seem to be motivated. In particular for oils spills, it seems likely that useful results can be obtained in a relatively near future provided that efforts are made in this direction.

References

- Abler, D., J. Shortle, J. Carmichael and R. Horan. 2002. Climate Change, Agriculture, and Water Quality in the Chesapeake Bay Region. *Climatic Change* 55(3):339-359.
- Arheimer B, J. Andréasson, S. Fogelberg, H. Johnsson, CB Pers and K. Persson. 2005. Climate Change Impact on Water Quality: Model Results from Southern Sweden. *Ambio* 34(7): 559–566
- Baresel, C., G. Destouni, and I-M. Gren. 2006. The influence of metal source uncertainty on cost-effective allocation of mine water pollution abatement in catchments. *Journal of Environmental Management* 78(2):138-148.
- Brady, M. 2003. The relative cost-efficiency of arable nitrogen management in Sweden. *Ecological Economics* 47(1):53-70.
- Byström, O., H. Andersson and I-M Gren. 2000. Economic criteria for using wetlands as nitrogen sinks under uncertainty. *Ecological Economics* 35(1):35-45.
- Champ, M.A. A review of organotin regulatory strategies, pending actions, related costs and benefits. *The Science of the Total Environment* 258(2000):21-71.
- Cohen, M.A. 1987. Optimal Enforcement Strategy to Prevent Oil Spills: An Application of a Principal-Agent Model with Moral Hazard. *Journal of Law and Economics* 30(1):23-51.
- Conrad, J.M. and L.J. Olson. 1992. The Economics of a Stock Pollutant: Aldicarb on Long Island. *Environmental and Resource Economics*, 2(3):245-258.
- COWI. 2007. Economics analysis of the BSAP with focus on eutrophication. Final report. April 2007.
- Elofsson, K. 2003. Cost-effective reductions of stochastic agricultural loads to the Baltic Sea. *Ecological Economics* 47(1):13-31.
- Elofsson, K. and I-M. Gren. 2004. Kostnadseffektivitet i svensk miljöpolitik för Östersjön – en utvärdering. *Ekonomisk Debatt* 3:57-68.
- Etkin, D.S. 2000. Worldwide Analysis of Marine Oil Spill Cleanup Cost Factors. Paper presented at Arctic and Marine Oilspill Program Technical Seminar, June 2000. Available 11/02/2008 at http://www.environmentalresearch.com/erc_papers/ERC_paper_2.pdf.
- Epple, D. and M. Visscher. 1984. Environmental Pollution: Modelling Occurrence, Detection, and Deterrence. *Journal of Law and Economics* 27(1):29-60.
- EU. 2001. Ambient air pollution by mercury (Hg). Position paper. Prepared by the Working Group on Mercury. Available 2008-10-02 at: http://www.europa.nl/environment/air/pdf/pp_mercury7.pdf
- EU. 2007. Scenar 2020 –Scenario study on agriculture and the rural world. DG Agri, Bryssel.

- Forslund, J., E. Samakovlis and M. Vredin Johansson. 2006. Matters Risk? The Allocation of Government Subsidies for Remediation of Contaminated Sites under the Local Investment Programme, Working Paper No 94, National Institute of Economic Research, Stockholm.
- Franzén, F, Å. Soutukorva and T. Söderqvist. 2006. Skagerraks miljö i samhälls-ekonomisk. belysning. Forum Skagerrak II. Enveco. Miljöekonomi. AB. 143 pp.
- Garpe, K. 2008. Ecosystem services provisioned by the Baltic Sea and Skagerrak. Report 5873. Swedish Environmental Protection Agency, Stockholm.
- Gren, I-M. 2000. Cost-effective nutrient reductions to the Baltic Sea. In Gren, I-M., K. Turner and F. Wulff. Managing a Sea. Earthscan, London.
- Gren, I-M. 2008. Costs and benefits from nutrient reductions to the Baltic Sea. Report 5877. Swedish Environmental Protection Agency, Stockholm.
- Gren, I-M., K. Elofsson och P. Jannke. 1997. Cost-effective nutrient reductions to the Baltic Sea. *Environmental and Resource Economics* 10:341-362.
- Gren, I-M. 2001. International versus national action against nitrogen pollution of the Baltic Sea. *Environmental and Resource Economics* 20:41-59.
- Gren, I-M. and F. Wulff. 2004. Cost effective nutrient reductions to coupled heterogeneous marine water basins: An application to the Baltic Sea. *Regional Environmental Change* 4(3):159-168.
- Harrington, W., R.D: Morgenstern and P. Nelson. 2000. On the Accuracy of Regulatory Cost Estimates. *Journal of Policy Analysis and Management* 19(2):297-322.
- Hart, R. och Brady, M. 2002. Nitrogen in the Baltic Sea – Policy Implications of Stock Effects. *Journal of Environmental Management* 66:91-103.
- Hart, R. 2002. Dynamic pollution control – time lags and optimal restoration of marine ecosystems. *Ecological Economics* 47(1):79-93.
- Hasselström, L. and T. Söderqvist. 2008. The economic value of ecosystem services provided by the Baltic Sea. Existing information and gaps of knowledge. Report 5874 Swedish Environmental Protection Agency, Stockholm.
- HELCOM. 1998. Final report on the implementation of the 1988 Ministerial Declaration. *Baltic Sea Environment Proceedings* No 17, Helsinki.
- HELCOM. 2001. The Implementation of the 1988 Ministerial Declaration on the Protection of the Marine Environment of the Baltic Sea Area with regard to Hazardous Substances. A final overall conclusion including the new goals.
- HELCOM. 2007a. Towards a Baltic Sea with environmentally friendly maritime activities. HELCOM Overview 2007. HELCOM Ministerial Meeting, Krakow, Poland, 15 November 2007.

- HELCOM. 2007b. Towards a Baltic Sea unaffected by hazardous substances. HELCOM Overview 2007. HELCOM Ministerial Meeting, Krakow, Poland, 15 November 2007.
- HELCOM. 2007c. HELCOM Baltic Sea Action Plan. HELCOM Ministerial Meeting, Krakow, Poland, 15 November 2007.
- Hjerne, O. and S. Hansson. 2002. The role of fish and fisheries in Baltic Sea nutrient dynamics. *Limnology and Oceanography* 47(4) 1023-1032.
- Jacobsen, B.H., J. Abildtrup, M. Andersen, T. Christensen, B. Hasler, Z.B. Hussain, H. Huusom, J.D. Jensen, J.S. Schou and J.E. Ørum. 2004: Omkostninger ved reduktion af landbrugets næringsstofftab til vandmiljøet – Forarbejde til Vandmiljøplan III. Fødevareøkonomisk Institut.
- Kiirikki, M., P. Rantanen, R. Varjopuro, A. Leppänen, M. Hiltunen, H. Pitkänen, P. Ekholm, E. Moukhametsina, A. Inkala, H. Kuosa and J. Sarkkula. 2003. Cost effective water protection in the Gulf of Finland: focus on St.Petersburg. *The Finnish Environment* 632. Finnish Environment Institute, Helsinki. 55 p.
- Knowler, D., E.B. Barbier and I. Strand. 2001. An Open-Access Model of Fisheries and Nutrient Enrichment in the Black Sea. *Marine Resource Economics* 16(3):195-217.
- Krupnick, A., D. Austin, B. Morton, V. McConnell, T. Stoessel and M. Cannon. 2005. The Chesapeake Bay and the Control of NO_x Emissions: A Policy Analysis. Discussion paper RFF-DP-98-46. Resources For the Future.
- Laukkanen, M. and A. Huhtala. 2007. Optimal management of a eutrophied coastal ecosystem: balancing agricultural and municipal abatement measures. *Journal of Environmental and Resource Economics* 39(2):139-159.
- Lehtonen, L., I. Bärlund, S. Tattari and M. Hildén. 2007. Combining dynamic economic analysis and environmental impact modelling: Addressing uncertainty and complexity of agricultural development. *Environmental Modelling and Software* 22:710-718.
- Neumann, T. and G. Schernewski. 2005. An ecological model evaluation of two nutrient abatement strategies for the Baltic Sea. *Journal of Marine Systems* 56(1-2):195-206.
- OECD. 2007. Instrument Mixes for Environmental Policy. OECD, Paris.
- OECD-FAO. 2007. OECD-FAO Agricultural Outlook 2007-2016. OECD, Paris.
- Ollikainen, M. and J. Honkatukia. 2001. Towards Efficient Pollution Control in the Baltic Sea: An Anatomy of Current Failure with Suggestions for Change. *Ambio* 30(4):245–253.
- Peirce, M., H. Jones, N. Passant and M. Holland. 2002. Cost Curves for the Abatement of Heavy Metal, PAH and Dioxin Emissions. Report produced for the Department for Environment, Food & Rural Affairs, the National Assembly for

Wales, the Scottish Executive and the Department of the Environment in Northern Ireland. AEAT/R/ENV/0159 Issue 1. AEA Technology Environment, Abingdon, Oxfordshire.

Petrolia, D.R. and P.H. Gowda. 2006. Missing the Boat: Midwest Farm Drainage and Gulf of Mexico Hypoxia. *Review of Agricultural Economics* 28(2):240-53.

Samakovlis, E., A. Huhtala, T. Bellander and M. Svartengren. 2005. Valuing health effects of air pollution - focus on concentration-response functions. *Journal of Urban Economics* 58(2):230-249.

Schou, J.S., S.T. Neye, T. Lundhede, L. Martinsen and B. Hasler. 2006. Modelling Cost-efficient Reductions of Nutrient Loads to the Baltic Sea . Model specification, Data and Cost-functions. NERI Technical Report No. 592. NERI, Copenhagen. 69 p.

Wallenius lines. 2006. Alfa Laval first with ballast water treatment system. Press release 26 September 2006. As available 1/31/2008 at http://www.walleniuslines.com/doc_upload/SMM_PR_060927.pdf .

Vandeven, J.A. and S.L. McGinnis. 2004. Cost-effectiveness of removing amalgam from dental wastewater. *Journal of Californian Dentists Association* 32(7):564-73.

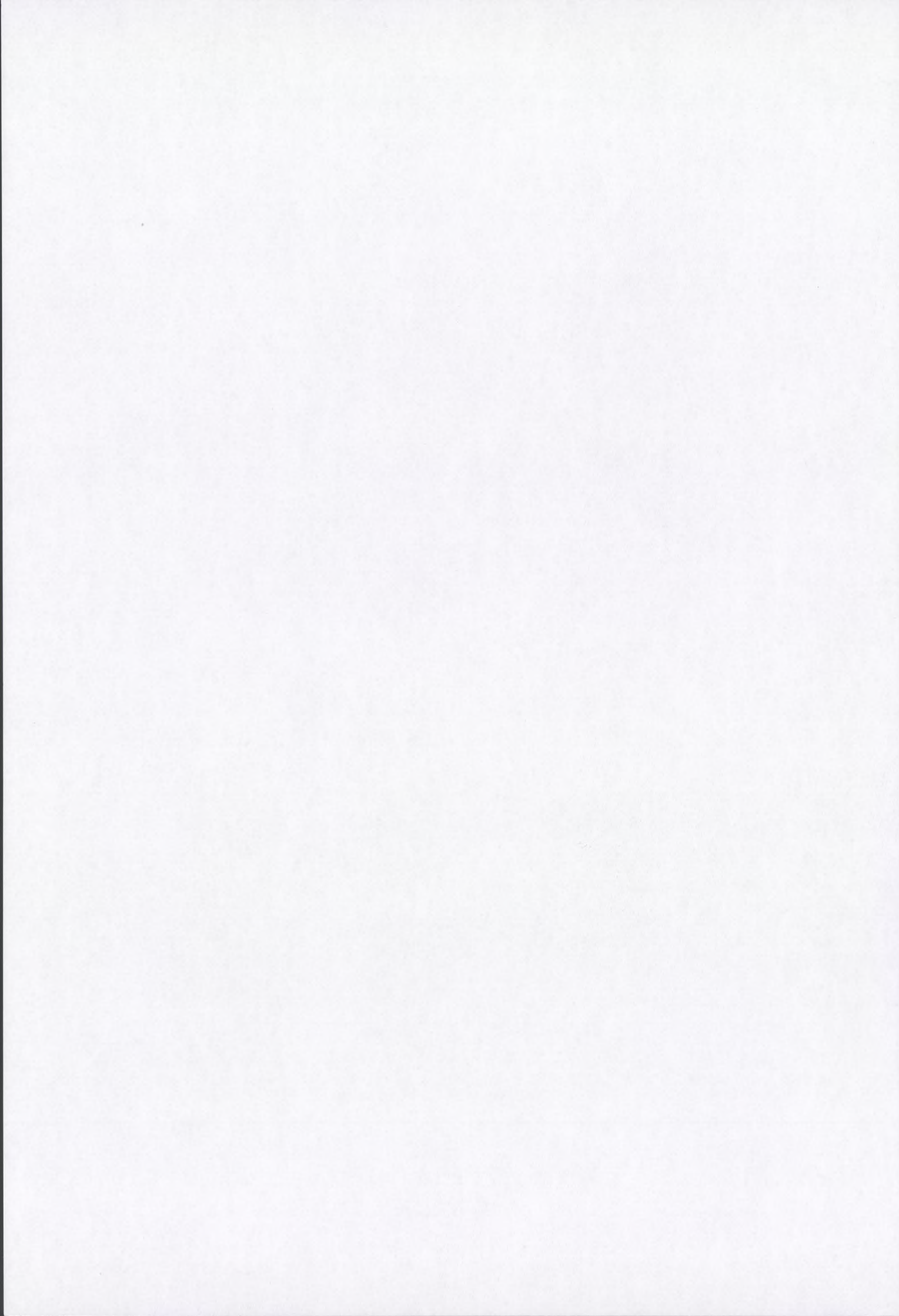
Östblom, G. 2007. Nitrogen and Sulphur Outcomes of a Carbon Emissions Target Excluding Traded Allowances - An Input - Output Analysis of the Swedish Case, Working Paper No 101. National Institute of Economic Research, Stockholm.

Östblom, G. and H. Hammar. 2007. Outcomes of a Swedish Kilometre Tax. An Analysis of Economic Effects and Effects on NOx Emissions, Working Paper no 103 National Institute of Economic Research, Stockholm.

Appendix

Table A1. Measures included in Baltic-wide studies:

Gren, Elofsson and Jannke (1997)	Elofsson (1999)	Ollikainen and Honkatukia (2001)	Schou et al. (2006)	COWI (2007)	Gren (2008)
<p><i>Agriculture:</i> Fertilizer reductions Wetland construction Catchcrops Energy forest Conversion to grassland Manure spreading time Livestock reductions (cattle, pig, poultry)</p>	<p><i>Agriculture:</i> Fertilizer reductions Catchcrops Winter crops Energy forest Conversion to grassland Buffer strips Manure spreading time Livestock reductions (cattle, pig, poultry)</p>	<p>Measures included in HELCOM reports</p>	<p><i>Agriculture:</i> Fertilizer reductions Wetland construction Catchcrops Livestock reductions (cattle, pig)</p>	<p><i>Agriculture:</i> Fertilizer reductions Catchcrops Conversion to grassland Buffer strips Manure management Livestock reductions (cattle, pig) Wetland construction</p>	<p><i>Agriculture:</i> Fertilizer reductions Wetland construction Catchcrops Energy forest Conversion to grassland Buffer strips Manure spreading time Livestock reductions (cattle, pig, poultry)</p>
<p><i>Transport sector:</i> Reductions in the use of motorfuels Catalysts in ships Catalysts in cars</p>				<p><i>Transport sector:</i> Catalysts in ships Catalysts in heavy vehicles</p>	<p><i>Transport sector:</i> Catalysts in ships Catalysts in cars</p>
<p><i>Energy sector:</i> Reductions in the use of fossil fuels SCR-technique</p>			<p><i>Energy sector:</i> SCR-technique</p>	<p><i>Energy sector:</i> SCR-technique</p>	<p><i>Energy sector:</i> SCR-technique</p>
<p><i>Waste water sector:</i> Improvements of waste water treatment plants</p>			<p><i>Waste water sector:</i> Improvements of waste water treatment plants</p>	<p><i>Waste water sector:</i> Improvements of WWTPs (primary, secondary incl. P abatement, tertiary cleaning) P-free detergents Private sewers</p>	<p><i>Waste water sector:</i> Improvements of waste water treatment plants P-free detergents Private sewers</p>



The costs of environmental improvements in the Baltic Sea and Skagerrak

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A review of the literature

This report provides a survey of studies regarding cost-effective strategies to meet environmental objectives for the Baltic Sea within the areas defined by the Baltic Sea Action Plan. The survey shows there is a rich empirical literature on the costs of reducing eutrophication in the Baltic Sea, while literature in other fields, such as hazardous substances and oil spills, could be developed in several directions.

The report is part of the project Economic Marine Information assigned by the Swedish Government.

