The Costs of a Cleaner Baltic Sea

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Introduction

The discharge of nitrogen and phosphorous to the Baltic Sea causes serious water quality problems with respect to eutrophication and oxygen deficits, causing ecological damage. Fisheries, recreation and marine biodiversity are threatened. The Baltic Sea is an international marine area, thus receiving pollutants from several countries, and an international approach is therefore necessary to make effective solutions. In 2007 the HELCOM (The Helsinki Committee), representing most of the countries around the Baltic Sea, made an agreement for the future of the Baltic Sea, in order to reduce the nutrient input to the sea and thereby avert further environmental damage. This is called the Baltic Sea Action Plan (BSAP), and an overall target of the plan is to reach a level of nutrient input, such that the Baltic Sea is unaffected by eutrophication (HELCOM 2007). The expiration year of fulfilment of the agreement is year 2016.

The Baltic Sea can be divided into 7 sea-regions in different current conditions and affected by continuous loading to different degrees. These sea-regions are Bothnian Bay (BB), Bothnian Sea (BS), Baltic Proper (BP), Gulf of Finland (GF), Gulf of Riga (GR), Danish Straits (DS) and Kattegat (KT). The Baltic Sea and the sea-regions can be seen from Figure 1.

In the BSAP the environmental importance of reaching certain limits for nutrients within these 7 sea-regions of the Baltic Sea is recognized. These limits imply some nutrient load reduction targets, which can be seen in Table 1.

Table 1: BSAP targets in sea-regions				
	Nitrogen		Phosphorous	
	Reduction (tonnes)	% of load	Reduction (tonnes)	% of load
BB	0	0,0	0	0,0
BS	0	0,0	0	0,0
BP	94.000	28,7	12.500	64,9
GF	6.000	5,3	2.000	29,2
GR	0	0,0	750	34,4
DS	15.000	32,7	0	0,0
KT	20.000	31,1	0	0,0
Total	135.000	18,3	15.250	42,0

Following these targets for reduction of nutrient loads in the sea-regions, the BSAP features an agreement on nutrient load reduction from riparian countries.
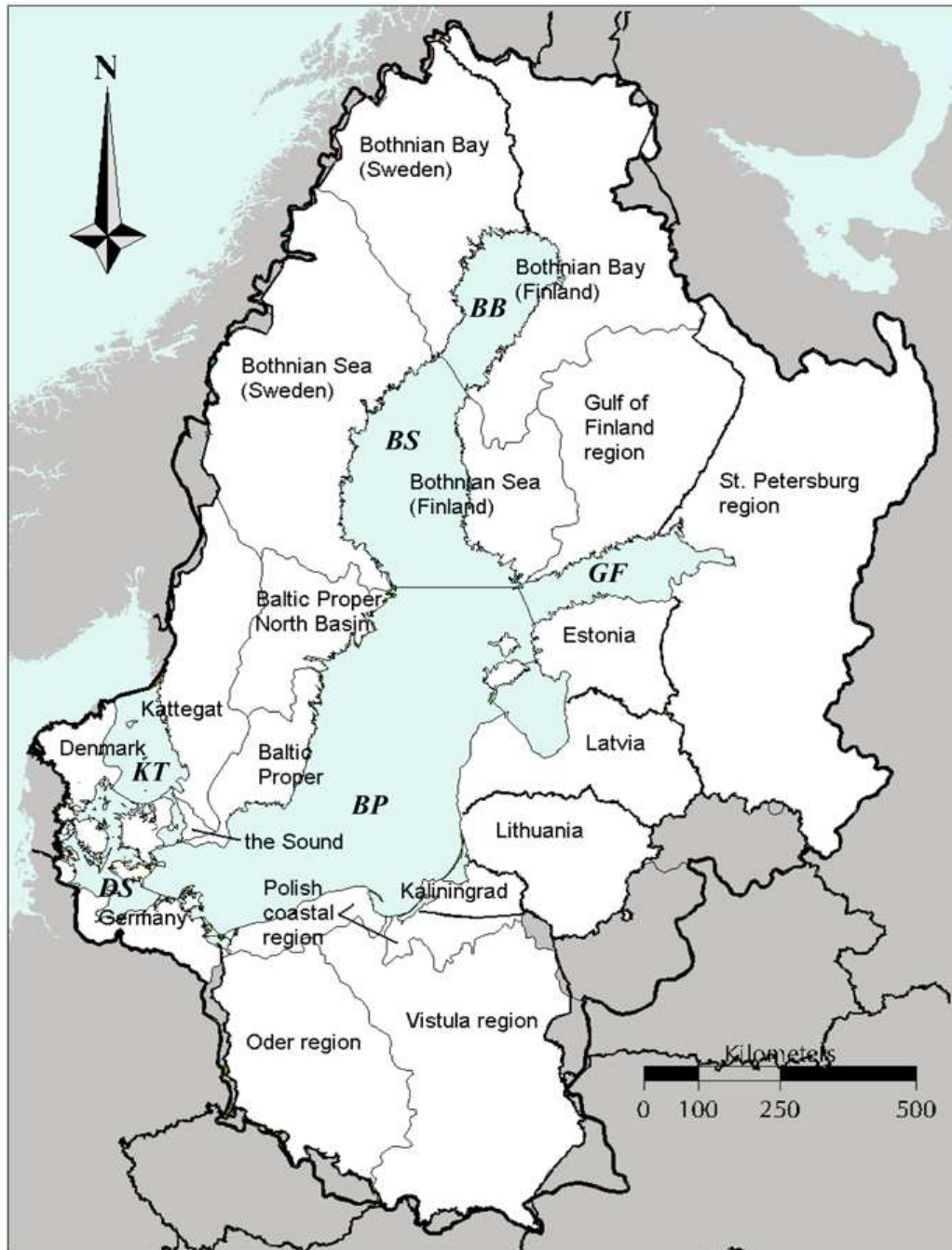
Figure 1: Map of the Baltic Sea indicating the 7 sea-regions and adjacent countries (from Gren and Wulff, 2004)

Hence, one of the key objectives of the BSAP is an agreement on nutrient reduction targets for each country bordering the Baltic Sea – the BSAP targets. BSAP requires ecological targets for each of the sea basins set by HELCOM, and the nutrient reduction required by each country are not decided to obtain cost-effectiveness, but so that each of the countries fulfill the national obligations for the EU waste water directive for the point sources. The reductions for the non-point sources and atmospheric emissions are distributed according to their relative contribution. The question of this study is whether the BSAP targets for each country represent the most cost-effective solution with respect to the regulation of the Baltic Sea or, if not, what is the difference in total costs between the cost effective solution and the BSAP solution?

From the BSAP, two sets of targets can be obtained. First, the nutrient reduction targets set on sea-regions, to obtain a good environmental status of each specific sea-region. These targets are only recognized, but not agreed upon. Second, there are targets set for each country, which is agreed upon - although there are no enforcement possibilities. An alternative would be to set a target for the entire sea, and estimate the most cost-effective distribution of actions between countries and sea regions. This is a scenario with an aggregate target for the entire Baltic Sea – the sum of targets on sea-regions – which is also presented. It will be assumed that all three targets are implemented cost-effectively.

The purpose of the study is to evaluate these three different approaches in terms of total costs, allocation between countries and environmental consequences for the sea-regions. This paper presents the cost minimization model used for the modelling of these scenarios, the cost minimizing solutions to the three different scenarios for fulfilling the targets in the Baltic, discussion of these results compared with other analysis in the Baltic as well as a discussion of how to use these results with respect to the WFD and the Marine strategy directive.

The Cost Minimization Model

A cost minimization model is developed for the Baltic Sea, embracing all sea regions and countries around the sea. Different versions of this model system exist. The first model was initially developed by Gren (2000) and Elofsson (2003), and later Schou et al (2006) developed a new model version. This model is now under further upgrading, development and extensions within the Baltic Nest Institute in Roskilde. The purpose of the model is to establish a framework for prescribing cost-minimizing solutions to the obtainment of different reduction targets for the nutrient inputs to the Baltic Sea by choosing the most cost-effective allocation of these abatement measures. The model is a cost-minimizing model for the reduction of nutrients into the Baltic Sea comprising all riparian countries, in which the level of some predefined measures is chosen. Six measures are considered, directed at either airborne or waterborne emissions.

The airborne emissions of nitrogen, NO_X emissions, e.g. from transport and power plants, constitute about 25% of the emission of nitrogen into the Baltic Sea, whereas there are no airborne emissions of phosphorous (HELCOM 2007). Approximately 40% of the airborne nitrogen emissions are originating in countries outside the Baltic Sea countries. The measure considered in the cost-minimization model in order to cut back the emissions of airborne nitrogen is installation of de-NOx units at power plants.

The waterborne emissions of nutrient originate from a number of sources. Agriculture is considered to be the major source of waterborne nutrient input to the Baltic Sea. In the cost minimization model this is dealt with by four measures: reduction of livestock, reduction in fertilizer use, planting catch-crops and establishing/restoring wetlands. The emissions are also partly due to (lack of) sewage treatment, measures considered to deal with not only improvement of existing sewage treatment, but also involves connecting households previously not connected to sewage treatment.

Each country connects to one or several sea-regions, and the specific combination of sea-region and one adjacent country is a pair, e.g. Poland-Baltic Proper is such a pair. These pairs are called drainage basins. The objective function is minimization of the overall cost of implementing the predefined measures in these drainage basins, i.e. the total abatement costs (*TC*). The cost minimization problem is a static problem, which for the sea-region targets can be described in a stylized way by:

$$\min_{x_i} \sum_i \sum_k TC_{ik}(x_{in})$$

$$s.t.$$

$$\sum_k g_{jn}(f_{in}(x_{ik})) \geq T_{jn}$$

$$x_{ik} \leq x_{ik,MAX}$$

The indexing is as follows: n indices nutrients, k measures, i drainage basins and j sea-regions. The sea-region target for sea-region j and nutrient n is denoted T_{jn}, while x_{ik} is the level of the measure k. The function f_{in} is the reduction of nutrient load resulting from the implementation of measures, hence showing the different impacts of the available measures. The maximum possible load reduction from policy measure k implemented in drainage basin i is denoted $x_{ik,MAX}$. The function g_{jn} describes the share of reduced emissions in drainage basin i effecting sea-region j, showing the effects of retention and transportation of nutrients in the Baltic Sea. Hence, the nutrient discharges to the sea from land and internal transportation of nutrients due to sea flow between the sea-regions are accounted for, which complicates compliance with the targets in each of the sea regions. Especially the Baltic Proper has a short coast-line relative to its magnitude, and is heavily affected by nutrient input to and from other sea regions, which makes it hard to reduce the nutrient flow to this sea-region adequately.

Different approaches can be chosen to model the transport between the sea-regions, and therefore different "transport matrices" for the transport of nutrients between the sea-regions are developed, based on input –output methodologies. We choose an approach inspired by (Gren et al, 2008); where a distinction is made between direct loads, first order adjustments and steady state. The direct loads are the emissions from a country to an adjacent sea-region. The first order adjustments are the immediate transportation of nutrients between connected sea-regions. Final adjustments to a steady state are likely to take place after decades, which are somewhat out of the scope of the present BSAP, since the maximum expiration year of fulfilment of the agreement is year 2016. Hence, only first order adjustments are accounted for here, since they occur rather rapidly.

Scenario Results

In the following, the three scenarios are presented and compared: One in which the BSAP targets for each sea-region is fulfilled, one where the BSAP targets set for each country are fulfilled[1], and finally one that sums up the recommendations based on sea-regions into an over-all nutrient load reduction target of the Baltic Sea – hence ignoring the need to consider the environmental impact on specific regions of the sea. The degree to which the 6 measures are used in each of the 9 countries is the choice variables of the models.

The sea-region targets describe the environmental effects, and they will be the departure point for the analysis. Compliance with the targets in all sea-regions is not achieved for all scenarios. In fact, the relatively high reduction targets for the Baltic Proper are only met in the first scenario (see Table 2.1 and 2.2), where they are required to be met. The following Table, Table 2.1, displays the reduction targets for nitrogen in the 7 sea-regions along with the actual reduction for each scenario, while Table 2.2 makes a similar comparison for phosphorous.

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[1] The country-wise and the sea region targets do not add up to the same total. The sea region targets are higher than the country targets. Further the country targets also have a transboundary common pool target which is not taken into account here.

Table 2.1: Reduction targets and effective reduction (tonnes N)				
	Scenario 1	Scenario 2	Scenario 3	BSAP Target
BB	1.713	423	0	0
BS	45.304	23.909	22.804	0
BP	126.592	38.326	55.765	94.000
GF	31.466	11.603	13.853	6.000
GR	13.879	3.599	13.113	0
DS	61.484	34.638	29.821	15.000
KT	31.336	15.703	0	20.000
Total	311.773	128.201	135.355	135.000

Table 2.2: Reduction targets and reduction in different scenarios (tonnes P)				
	Scenario 1	Scenario 2	Scenario 3	BSAP Target
BB	86	62	0	0
BS	3.444	2.074	2.650	0
BP	12.500	1.686	4.263	12.500
GF	4.486	2.486	3.461	2.000
GR	750	332	594	750
DS	5.502	3.290	4.281	0
KT	887	138	0	0
Total	27.655	10.068	15.250	15.250

When comparing the results of the second scenario (country) with the sea-region targets, it is evident that several of the sea-region targets are not met by the proposed allocation between countries. The reduction in Kattegat is 79% of the corresponding sea-region target for nitrogen. It is even worse for the Baltic Proper, since the reduction of nitrogen in the Baltic Proper is only about 41% and the reduction of phosphorous in the Baltic Proper is approximately 13% of the target for this sea-region. It is worth noticing that due to transportation of nutrients, the reduction targets for phosphorous in the Baltic Proper cannot be met by reducing the direct loads to the Baltic Proper, since such direct loads are transported of to the surrounding sea-regions, i.e. the Gulf of Finland, the Danish Straits, the Bothnian Sea and to a smaller extent the Gulf of Riga. The phosphorous target can only be met by reducing in the adjacent sea-regions, transporting some of the load directly emitted into them further on to the Baltic Proper. This holds for the above mentioned sea-regions, which passes between 9% and 81% of the direct discharges of phosphorous into them further on to the Baltic Proper. For nitrogen goes that reducing discharges directly to the Baltic Proper will have some effect, but a greater impact will still be achieved by reducing in the Bothnian Sea, the Gulf of Finland and the Gulf of Riga. To achieve a higher reduction in the Baltic Proper, the countries adjacent to these sea-regions should reduce more, especially the Bothnian Sea and the Gulf of Finland, which have the highest contribution of both nutrients. This implicates that primarily Finland, Russia, Estonia and Sweden should make more reductions.

Not surprisingly, the targets are not met by setting an aggregate target for the Baltic Sea either.

The costs of these three scenarios are compared for each scenario. The total cost from each of the three scenarios appears in Table 3.

Table 3: Costs of implementation in countries (Euro per year)			
	Scenario 1	Scenario 2	Scenario 3
SE	431.669.925	119.202.790	0
FI	283.417.601	7.300.458	0
RU	402.802.250	53.272.451	99.433.600
EE	109.735.601	4.687.976	3.741.882
LV	100.151.682	4.458.520	37.373.927
LT	121.063.554	8.097.918	36.180.922
PL	408.716.799	199.502.073	217.855.619
DK	587.157.236	54.066.013	0
DE	166.739.720	21.564.139	0
Total	2.611.454.368	472.152.337	394.585.949

The cost of fulfilling the sea-region target is about 6 times higher than fulfilling either of the two latter targets, as this target forces another distribution of action between countries and to each of the countries. Complying with the phosphorous targets in the Baltic Proper and Gulf of Riga is extremely difficult, and this lead to over-compliance of all other targets for nitrogen and phosphorous, due to transportation. Hence, the over-all reduction of nutrients is 2-3 times greater than for the second and third scenario. Because marginal abatement costs are increasing, this leads to the high total cost.

In line with intuition, it turns out to be more expensive to comply with the targets in either one of the first two scenarios than to comply with the aggregate target. Even though setting an aggregate target is considerably cheaper, it holds its disadvantages. By setting an aggregate target, the condition of the ecosystems in the specific sea regions is not considered, although they hold different ecological properties, e.g. due to transportation of nutrients via sea-flow. Neither is the distribution of costs between countries considered.

The second scenario, where targets are set per country, turn out to be a bit more expensive, in spite of the fact that the aggregate target for countries is slightly lower in this scenario than in the third scenario, which is an aggregation of targets set per sea region. This is the additional cost of constraining solution by predefining the allocation between countries, and hence cost-effectiveness is not obtained compared to an aggregate solution. The solution can be advocated for in terms of the distributional effects, as this solution leads to a more even distribution between countries. The aggregate solution leads to very different distribution of costs between countries, as well as in effective loads between sea regions, as seen in Tables 2.1, 2.2 and 3.

To reveal how the allocation is distorted compared to the cost-effective solution, the allocation of reductions between countries are displayed in percentage of total reduction in the respective scenarios.

Table 4.1: Reductions of loads of nitrogen in countries (%)			
	Scenario 1	Scenario 2	Scenario 3
SE	12,4	14,1	0,0
FI	4,8	2,0	0,0
RU	16,4	9,1	16,1
EE	6,0	0,8	0,7
LV	8,4	4,1	25,0
LT	8,8	12,0	22,8
PL	26,5	42,4	35,4
DK	11,4	11,7	0,0
DE	5,4	3,8	0,0

Table 4.2: Reductions of loads of phosphorus in countries (%)			
	Scenario 1	Scenario 2	Scenario 3
SE	4,4	2,9	0,0
FI	1,9	1,1	0,0
RU	22,1	18,6	23,6
EE	4,5	1,6	0,9
LV	7,8	2,2	11,0
LT	9,0	6,5	12,8
PL	43,6	65,1	51,7
DK	4,7	0,1	0,0
DE	1,9	1,8	0,0

What is revealed by the Tables is how the allocation between countries varies depending on target-setting. This is most explicitly seen in the solution for the aggregate target, where the cheapest measures are suggested disregarding country and location relative to the sea regions. In this scenario, only five countries should make reductions; hereof Latvia and Lithuania should reduce the most. This is easily explained by cheaper measures in these countries, which again is due to low opportunity costs for e.g. establishing wetlands. Another reason for this is the rather large potential in these countries, where improved sewage treatment is supposed to have enormous effects[2].

Regardless of the target setting, Poland should make the biggest reduction of both nutrients. Reduction in the scenario with the aggregate target is set, because Poland have the potential to increase the use of the relatively cheap measure sewage treatment. However, the share of reduction in Poland is relatively smaller in the first scenario (specific sea region targets); although the location of Poland near the Baltic Proper would lead to believe that Poland should make more reductions. However, as previously discussed, accounting for transportation changes this picture. Since Poland does not make direct discharges into the sea-regions adjacent to the Baltic Proper, the direct discharges from Poland only have a minor impact on the level of nitrogen in the Baltic Proper and no impact on the level of phosphorous in the Baltic Proper. Hence, even though it is relatively cheap to make reductions in Poland, and even though it can seem fair to make these reductions because of initial loads, the relatively low impact of such reduction in relation to key targets gives preferential treatment to Poland.

The cost-effective solution for Poland to meet these reductions is only sewage in the third scenario. In the second scenario, relative higher cuts are necessary for Poland, but they are met by, on one hand, implementing slightly less sewage than in the third scenario, but on the other hand to implement the additional measure of establishing wetlands. This results even though sewage is cheaper, because wetlands are more effective in reducing nitrogen relative to phosphorous than sewage. Hence, it is the cheapest way of meeting the twofold target of both nitrogen and phosphorus reductions for Poland. In the first scenario, the extent of the needed reduction leads to every measure being used to different degrees.

Summary

First of all, the minimum total cost of improving the Baltic Sea and the allocation between countries of reductions and the following costs, differs due to the specific target-setting. This is important to be

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[2] For Sweden, Denmark, Finland and Germany it is assumed that sewage treatment is optimal, i.e. there is no potential for improved sewage treatment in these countries.

aware of these consequences when specifying targets, as done in the BSAP. This result is also relevant for the WFD and the Marine Strategy Directive.

The seemingly harmless difference between the two sets of targets leads to major differences in especially cost, but also in allocation between countries. Furthermore, if the sea-region targets in BSAP are set to protect the ecosystem of certain vulnerable sea-region, hereby especially the Baltic Proper, this objective is not met by the proposed allocation for countries. In order to protect these sea-regions, much higher reductions than immediately perceived are necessary. The vulnerable sea-regions are in their current condition due to the same circumstance, which makes it hard to make reductions – i.e. transportation of nutrients.

Comparing the cost-effective solution for sea-regions with the allocation proposed by the targets set for countries, there is a difference in distribution of costs across countries. This reveals how the BSAP agreement of distribution of reductions between countries is distorted compared to a cost-effective solution.

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