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TOWARDS EFFICIENT POLLUTION CONTROL IN THE BALTIC SEA

An anatomy of current failure with suggestions

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ABSTRACT: We study the Baltic Sea countries' declaration to reduce nutrient loads by 50% in each country in an ecological-economic model. The model consists of country-based abatement cost functions, and transfer coefficients describing how phosphorus and nitrogen flow from one country to another, as estimated in a hydrological model of the Baltic Sea. We show that for nitrogen in particular the overall abatement costs of the current policy are much higher and that the benefits are more uneven than under a cost-efficient policy. Consequently, one can expect that countries with high marginal abatement costs have the least incentives to follow the agreement and to invest in nitrogen abatement. This is also confirmed by our data. Therefore, we suggest and outline a joint implementation policy to promote cost-efficiency and to increase incentives for investments.

Keywords: nitrogen, phosphorus, cost-efficiency, joint implementation

JEL Classification: Q25, Q28

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TIIVISTELMÄ: Tässä tutkimuksessa tarkastellaan ympäristötaloudellisen (ekologis-taloudellisen) mallin avulla Itämeren maiden julistusta vähentää ravinnepäästöjä 50% kussakin maassa. Malli koostuu maakohtaisista puhdistuskustannusfunktioista ja hydrologisen mallin avulla estimoiduista typen ja fosforin kulkeutumiskertoimista. Tutkimuksessa osoitetaan, että Itämeren maiden omaksuman ympäristöpolitiikan kustannukset ovat erityisesti typen osalta merkittävästi korkeammat ja suojelun hyödyt epätasaisemmin jakautuneet kuin kustannustehokkaassa ympäristöpolitiikassa. Tämän vuoksi puhdistuskustannuksiltaan kalliiden maiden kannustimet typpipäästöjen vähentämi- seen ovat vähäiset. Tätä johtopäätöstä tukevat myös tiedot toteutuneista ravinnepäästöstä. Tutkimuksessa ehdotetaan ja hahmotellaan yhteistoteutusta keinona edistää kustannustehokkuutta ja lisätä kannustimia suojeluinvestointeihin.

Avainsanat: typpi, fosfori, kustannustehokkuus, yhteistoteutus

JEL- luokitus: Q25, Q28

ESIPUHE

Tässä raportoitava tutkimus on osa laajempaa taustapaperia, joka on valmistettu ympäristöministeriön käyttöön. Taustapaperin tutkimuksellinen ydinosa, kustannustehokkaan politiikan ja yhteistoteutuksen analyysi, on laadittu myös tieteellistä julkaisutoimintaa silmälläpitäen. Se on hyväksytty julkaistavaksi Ambio-lehdessä. Näiltä osin tekijät kiittävät kahta anonyymia refereetä, Erik Bonsdorffia sekä Man and the Baltic Sea -Symposiumin osallistujia rakentavista kommenteista. Koko taustapaperin suhteen olemme saaneet rakentavaa ohjausta ja kommentteja ympäristöministeriön vanhemmalta tutkijalta Timo Parkkiselta. Tutkimusta on tehty osana ja tiiviissä yhteistyössä ympäristöklusterihankkeen "Kustannustehokkaat vesiensuojelutoimenpiteet Suomenlahdella" kanssa. Juha Sarkkulan ja Mikko Kiirikin (Syke) neuvot sekä Jorma Koposen ja Arto Inkalan (YVA) tutkimus fosforin ja typen kulkeutumisen osalta ovat olleet ratkaisevan tärkeitä tutkimuksen toteuttamiseksi. Tutkimuksen laajan tausta-aineiston keräämisessä ja analysoimisessa ovat avustaneet Johanna Alatalo ja Sinikka Littu.

Helsingissä 29.3. 2001

Juha Honkatukia Markku Ollikainen

1 INTRODUCTION

In 1974 the Baltic Sea countries signed an agreement about marine pollution control in the Baltic Sea. This agreement was historical. For the first time all countries around a sea area were jointly willing to manage the quality of the sea. The background for the agreement was a rapid increase of poisonous pollutants such as DDT, PCB and PCT, which not only deteriorated the quality of the aquatic system, but also provided a threat to human health. The Baltic Sea agreement turned out to be very successful in reducing poisonous pollutants. Therefore, in 1988 the respective ministries of the environment decided to strengthen and also to modify this policy. According to Helcom (1994): "At the 1988 Ministerial Meeting the Ministers of the Environment declared their firm determination to reduce substantially the inputs of heavy metals, toxic or persistent organic compounds and nutrients, e.g. in the order of 50 per cent by the year 1995."

After the declaration, the Baltic Sea countries started to devote more attention to the reduction of nutrient pollution caused jointly by nitrogen and phosphorus leaching. The littoral countries and their joint organization, the Helsinki Commission have worked hard to achieve this target. One important approach has been listing the so-called hot spots, for which the most urgent reductions are required. Still**,** reading newspapers gives one the impression that the goals of a 50% reduction have not been fulfilled. A look at the statistical information confirms this impression. It seems that especially the nitrogen load to the Baltic Sea has decreased very slowly. This observation raises many questions. Why have the Baltic Sea countries so far failed to achieve the 50% reduction target? How well founded is this kind of target generally? Could we find a better allocation of the reduction across the countries in terms of water quality in each part of the Baltic Sea and in terms of costs and benefit to countries. Moreover, by what means could we promote it?

Answering the questions is far from trivial. In the case of the Baltic Sea, differences in benefits and costs are closely associated to differences in the abatement technology and the transfer of pollutants in the sea, and hence to a country's location. Obviously, for countries, which already have invested in abatement of nitrogen and phosphorus, an achievement of a 50% reduction is more costly than for those, which have done nothing or have only done a little. The role of a country's location is more intriguing. Given that nutrient loads is transferred across sub-regions, a "dirty" country may count on the fact that even a considerable share of its pollution may transfer to its neighbor's coastal waters. Hence, the polluter country benefits from savings in abatement costs.

The economic theory of international environmental agreements, suggests the use of the following three-step approach to the study of economic-ecological content of nutrient reduction in the Baltic Sea by an international agreement.[1] In step 1, the necessary basic information base is formed. This includes information on the nutritive loads from rivers (and air) to the Baltic Sea; estimations of how nutrients flow from one sub-region to another; description of the algae blooming in each part of the sea, and the estimates for the abatement costs of nutrients in each country. Step 2 consists of the determination of overall nutrient reductions and their allocation to each country by applying economically sound decisions (optimality or cost-efficiency). Step 3 is necessary to ensure the commitment of each country to the agreement. It includes the analysis of the incentives of each country to fol-

[1] For analyses of negotiation in the case of regional, transboundary pollution, see for instance, Mäler 1993, Tahvonen et al. 1993, Kaitala et al. 1995, and in the case of global pollutants, Barret 1990.

low the agreement. This means, among other things, checking how the costs and benefits are distributed among countries; designing a monetary system to distribute the net benefits more evenly across countries, and designing organizations – if necessary – for the fulfillment of the agreement. By this procedure, environmental economic analysis combines ecological and economic information into a single framework, in which economic incentives and costs affect each country's discharge of nutritive loads into the Baltic Sea. This load, in turn, determines the water quality in various sub-regions of the Baltic Sea.

We apply this framework to study the economic content of the 50% declaration as an agreement, and an alternative, cost-efficient design for this kind of declaration in the Baltic Sea. We show that how the reduction target is formulated (both in magnitude and in the allocation across countries) matters a lot in terms of costs and benefits from the pollution reduction. A poorly formulated agreement leads to unevenly distributed costs and benefits between the countries, and if this is the case one cannot expect all countries to follow the agreement.

More specifically, we address the problems of controlling both nitrogen and phosphorus loads separately, just as treated in the declaration.[2] For the analysis, we distinguish between various sub-regions of the Baltic Sea, and all countries (see Figure 1 below). We use data from Helcom to estimate the abatement costs of nitrogen and phosphorus. Furthermore, we utilize information from a hydrological model of the Baltic Sea to describe how nitrogen and phosphorus transfer from each polluting country to neighboring areas, in order to solve the resulting loads in each country's coastal waters. Based on these, we compare the 50% reduction target for both nutrients with a cost-efficient solution, which yields the same overall reduction. We supplement the cost data with estimates of the aggregate amounts of nutrients in each country as a proxy for damages, because we do not have data of pollution damages. Then we discuss the countries' incentives to follow the declaration and briefly sketch the new directions that could be adopted in the fine tuning of the efforts for reducing the nutritive load in the Baltic Sea.

The paper is organized as follows. Section 2 develops the theoretical model, which includes a description of pollution process and a discussion on non-cooperation and cooperation between Baltic Sea countries. Section 3 is devoted to a simulation model. Results of simulations are given in section 4, which is followed by a short concluding section.

2 THEORETICAL FRAMEWORK FOR A POLLUTION REDUCTION AGREEMENT

2.1 Basic Model of Pollution Control in the Baltic Sea

The flow of nutrient pollutants to the Baltic Sea comes from both air and rivers. Besides the nine contracting Baltic Sea countries of Denmark, Estonia, Germany, Finland, Lithuania, Latvia, Poland, Russia, and Sweden, the catchment area of the Baltic Sea also includes the Czech Republic, Slovakia, Norway, Ukraine and Belorussia. In Figure 1 we indicate the catchment area, and the Helcom division of the Baltic Sea in sub-regions, which are

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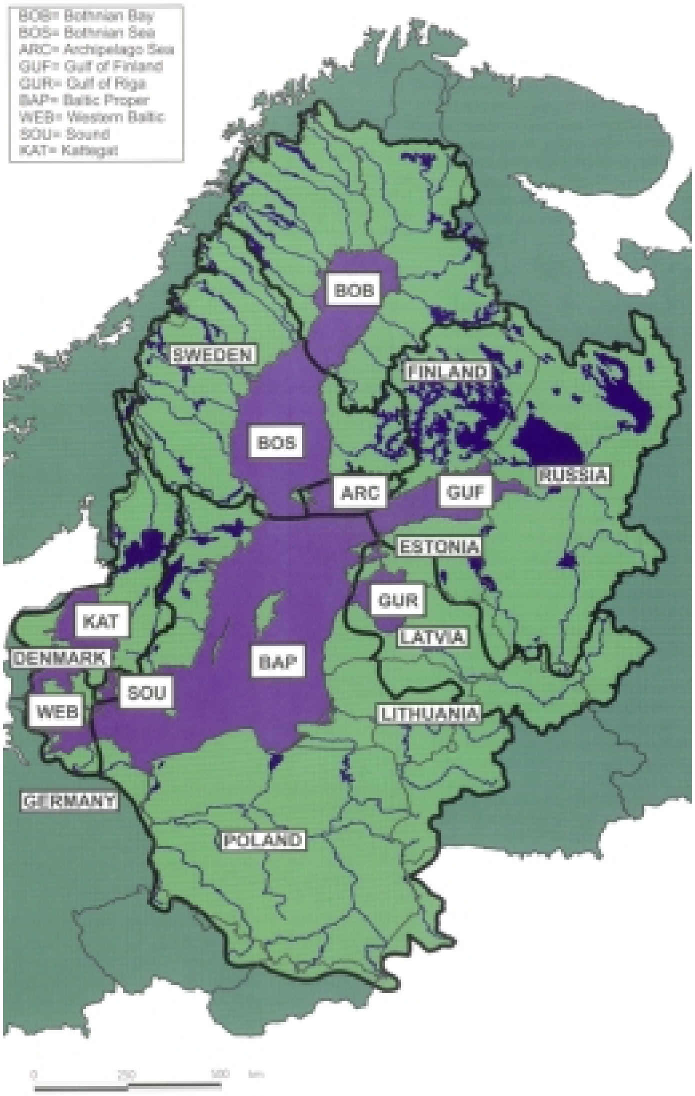
[2] Literature concerning the pollution control in the Baltic Sea is not large. Note, however, Gren et al. 1997, Gren 1998, and Gren et al. 2000, which have a similar approach to ours.

Bothnian Bay, Bothnian Sea, Archipelago Sea, Gulf of Finland, Gulf of Riga, Baltic Proper, Western Baltic, The Sound and The Kattegat.

Figure 1. Baltic Sea and its sub-regions



Source: HELCOM

Nutrient load causes eutrophication, which damages all countries. We describe the damage function of eutrophication, e, in each country, i, by:

[1] $d_i = d_i(e_i)$, $i = 1 \ldots 9$.

where e is the joint product of the overall amounts of nitrogen N_i and phosphorus P_i. The damage function is assumed to be convex, i.e., $d_i' > 0$ and $d_i'' > 0$, indicating that damage increases with pollution.

The aggregate amounts of nitrogen and phosphorus in each country's seawater will depend on the domestic loads, as well as on the transfer of nitrogen and phosphorus with sea streams and wind from other countries. This transfer process can be described with the help of the following transfer matrix, where each transfer coefficient a_{ij} indicates what share of a country's j nitrogen or phosphorus transfers to country's i waterways.

$$[2] \qquad A = \begin{vmatrix} a_{11} & . & . & . & a_{91} \\ . & . & & & . \\ . & & a_{55} & & . \\ . & & & . & . \\ a_{19} & . & . & . & .a_{99} \end{vmatrix},$$

The aggregate concentration of nitrogen N_i accruing to a country i is, thus, given by $N_i = \sum_{j=1}^{9} a_{ji} n_j$, where n_j refers to country's j nitrogen effluent. When [2] describes phosphorus, we have $P_i = \sum_{j=1}^{9} a_{ji} p_j$, where p_j refer to country's j phosphorus effluent.

Finally, there are abatement technologies for reducing nitrogen and phosphorus. They typically have the property that initial reductions can be achieved easily, but further reduction become more and more difficult. This feature can be described by the abatement cost functions for nitrogen and phosphorus, respectively

$$[3] \qquad c_i(n_i) \text{ and } c_i(p_i), \text{ with } c' > 0 \text{ and } c'' > 0.$$

Consider any single country in the area of the Baltic Sea. Its total costs of pollution are given by the sum of damage and abatement costs. Because we analyze nitrogen and phosphorus control separately, we express the total costs of pollution for one effluent (nitrogen) only. Similar equations will hold for phosphorus.

$$[4] \qquad J_i = d_i(N_i) + c_i(n_i),$$

where N_i is defined by equation [2].

Based on equation [4] we characterize two alternative solutions for the pollution control policy. First, we assume that a country will not cooperate but searches for a domestic policy (non-cooperative Nash solution). Of the possible cooperative solutions, we characterize both optimal and cost-efficient agreements, because both serve our empirical analysis.

2.2 Domestic non-cooperative pollution control policy

Assume that the countries do not cooperate and take the abatement choices of the other countries as given, when choosing their own abatement policies. In that case the solution is straightforward: the country simply chooses the abatement levels of nitrogen so as to minimize the domestic costs of pollution

[5] $$\underset{\{n_i\}}{Min}\, J_i = d_i(N_i) + c_i(n_i)$$

Minimizing this target function gives the national environmental policy the following abatement rule: $a_{ii} d_i'(N_i) = -c_i(n_i)$. According to this the country reduces its nitrogen pollution up to the point where the marginal damage from pollution in that country (transfer coefficient a_{ii} indicates the share of the load remaining within the country) equals the marginal abatement cost. This abatement rule also holds for phosphorus reduction.

The optimal reduction of nitrogen or phosphorus effluent according to this policy rule, is illustrated below in Figure 2 by point A where the domestic marginal abatement curve (MAC) and domestic marginal damage curve (MDC) intersect. The optimal domestic reduction, n_d^*, can be read from the horizontal axis.

This optimum, however, is problematic from the "global viewpoint", i.e., when the whole Baltic Sea is considered. Here each country takes into account only the resulting domestic damages, not the damage caused to other countries. Moreover, the solution is conditional on the other countries' abatement choices, i.e., on the externalities caused by other countries. Hence, one can conclude that the resulting Nash equilibrium is sub-optimal from the viewpoint of the whole Baltic Sea, because none of the countries takes into account the externality it causes to other countries. Consequently, the pollution level remains too high. This calls for international cooperation.

2.3 Cooperative International Environmental Policy

Assume in conformity with reality that the countries decide to make an agreement for a pollution reduction. By making such an agreement the countries declare that pollution is a severe problem and acknowledge their responsibility for it. There are, however, many options for the type of agreement. In the case of the Baltic Sea the actual agreement can be called *a 50% club solution*, because each country decided to reduce both phosphorus and nitrogen by 50% regardless of the costs and benefits accruing to each of them. Economic theory suggests that a more adequate form of an agreement to achieve 50% reduction is to make it cost-effectively, i.e., to achieve the reduction with minimum cost (*cost-effective solution*). An alternative would naturally be an *optimal solution*, where the reduction target is defined on the basis of costs and benefits from abatement.

A. Optimal Environmental Policy

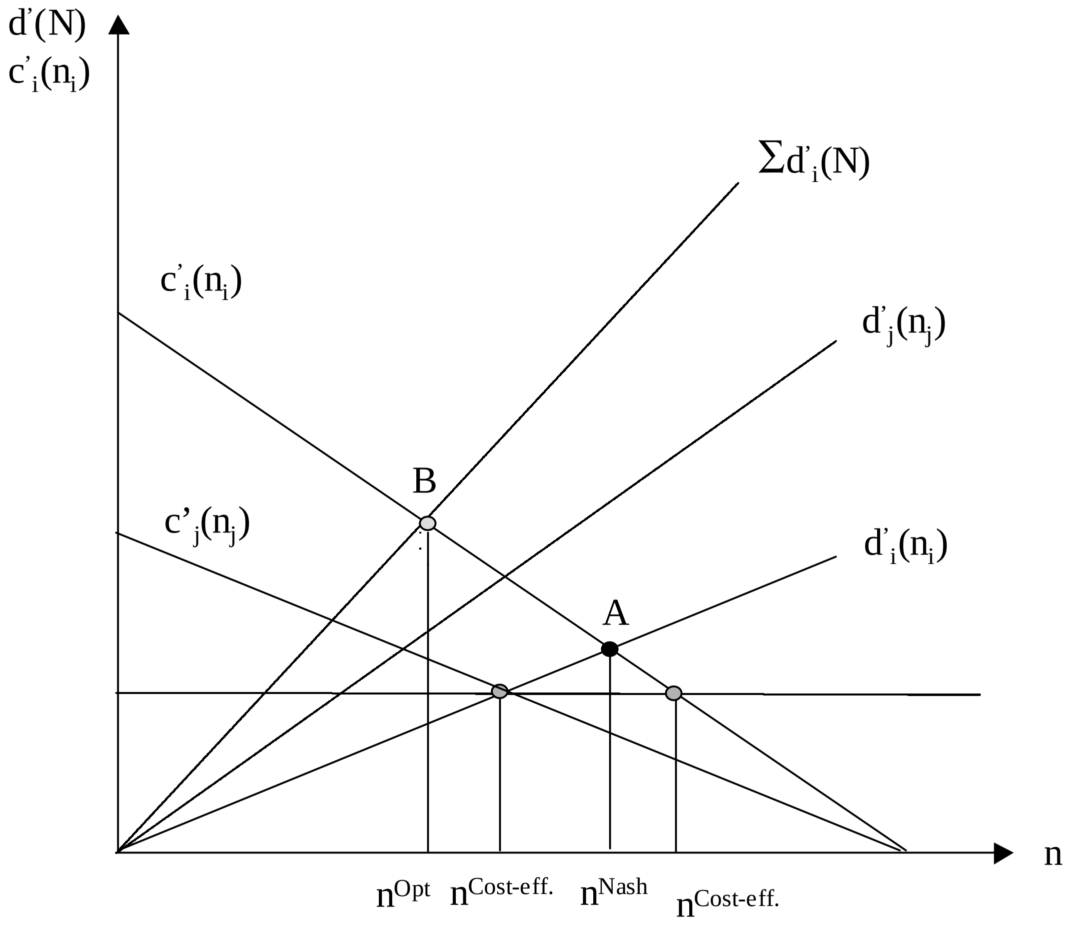
When the countries search for the "globally" optimal solution they minimize the sum of each country's costs from pollution by choosing optimal levels of nitrogen reductions.

[6] $$\min_{\{n_1 \dots n_9\}} J = \sum_{i=1}^{9} (d(N_i) + c_i(n_i))$$

subject to [2].

As one can see, equation [6] clearly differs from the respective Nash target function [5], because it takes into account the fact that nitrogen pollutants transfer with sea streams and winds causing externalities to other countries in the Baltic Sea. Choosing national abatement levels by accounting for damages caused by domestic pollution to other countries yields the optimality condition: $d'(N)\sum_{j=1}^{n} a_{ji} = -c_i(n_i)$. This optimal cooperative environmental policy rule advises each county to abate nitrogen up to the point where the aggregate marginal damage caused by domestic pollution equals the domestic marginal abatement costs. It can be illustrated graphically as point B in Figure 2. Notice that it implies a higher level of abatement than point A, which reflects a purely domestic non-cooperative abatement rule.

Figure 3. Non-cooperative and cooperative solutions



B. Cost-Efficient Environmental Policy

If it is hard or impossible to identify the costs of damages, countries have to rely on a second best approach. The desired level of pollution abatement is determined on the basis of all scientific and other information available. After the desired level has been decided, the task of the environmental authorities is to achieve this goal with the least cost. Hence, the cost-efficient international agreement for both nitrogen and phosphorus reduction is obtained by minimizing the sum of abatement costs across countries, subject to the predetermined level of abatement and irrespective of the concentration of the nitrogen in the sub-regions of the Baltic Sea:

[7] $$\min_{\{n_1 \ldots n_9\}} J = \sum_{i=1}^{9} (c_i(n_i)$$

subject to $$\sum_{i=1}^{9} n_i \leq \overline{N},$$

where $\overline{N}$ is defined as 50% of the respective levels for the base year 1990.

The cost-efficient solution to problem [7] yields the following cost-efficient rule for cooperative environmental policy: allocate the abatement obligation to all countries so that the marginal abatement costs across countries will be equal at the required level of reduction. This policy implies that each country contributes equally at the margin so that the countries with low abatement costs will reduce nitrogen and phosphorus more than countries with higher abatement costs. In Figure 2 this solution can be illustrated by a horizontal line defining equal level of all national marginal abatement cost curves at the required reduction overall target (as a sum of national reductions). Notice that also in this case those countries abate most for whom the marginal abatement costs are the cheapest.

The club, optimal and cost-efficient solutions will provide the basic cases for the simulations and discussion in the next two sections. We compare the club solution to the cost-efficient solution also by augmenting the cost-estimates with the estimates of national loads of nitrogen and phosphorus as a proxy for damages, because we do not have monetary estimates for marginal damages.

3 NITROGEN AND PHOSPHORUS LOADS AND THEIR ABATEMENT COST FUNCTIONS

This section is devoted to presenting the basic data of nutrient loads into the Baltic Sea and to developing the abatement cost functions of nitrogen and phosphorus. Moreover, we calculate the transfer coefficients to describe the flow of country-based nitrogen across various sub-regions of the Baltic Sea. We base our analysis on the Helcom data, out of which the most important sources are Helcom 1993a, 1993b, 1993c, 1998a and 1998b and the Activity Inventories for 1992-8 reporting actions taken in the hot spots specified by the Baltic Sea Joint Comprehensive Environmental Action Programme.

3.1 Loads, transfer and concentration of nitrogen pollution

We have used a hydronomic model of the Baltic Sea developed by Koponen and Inkala to produce estimates for the transfer of nitrogen and phosphorus.[3] The estimates describe the

[3] See Koponen et al. 1994 for the general presentation of the model, Sarkkula et.al. 2000 for a demonstrative model based on the general model, and Kiirikki et al. 2000 for the model's application to the Gulf of Finland)

content of these nutrients in the surface water (up to 20 meters) in the coastal area (up to about 15 kilometers from the coast). The time period of the hydronomic model was set at six years and the coefficients were determined as the average values of the sixth year. We obtained an asymmetric pollution transfer matrix by aggregating over the sub-regions adjacent to each country. The transfer of nitrogen and phosphorus can be described by a 9x9 matrix, where the polluting country is given in columns and the pollution receiving country in rows. Hence, the diagonal indicates the share of nitrogen staying in the polluter country. Naturally, the sum of all the transfer coefficients for each polluting country is equal to unity. The transfer of nitrogen and phosphorus is shown in Tables 1 and 2, respectively.

Table 1. The transfer of nitrogen across countries

	Denmark	Estonia	Finland	Germany	Latvia	Lithuania	Poland	Sweden	Russia
Denmark	0.61	0	0	0.09	0	0.01	0.24	0.06	0
Estonia	0	0.2	0.11	0	0.24	0.01	0.01	0.04	0.4
Finland	0	0.09	0.33	0	0.02	0	0	0.08	0.48
Germany	0.34	0	0	0.09	0	0.02	0.52	0.03	0
Latvia	0	0.05	0	0	0.85	0.03	0.04	0.02	0
Lithuania	0.01	0	0	0	0.03	0.6	0.29	0.03	0.02
Poland	0.03	0	0	0.01	0	0.04	0.88	0.02	0.01
Sweden	0.24	0.01	0.07	0.04	0.03	0.05	0.3	0.25	0.01
Russia	0.01	0.04	0.03	0	0.01	0.05	0.41	0.01	0.45

Table 2. The transfer of phosphorus across countries

	Denmark	Estonia	Finland	Germany	Latvia	Lithuania	Poland	Sweden	Russia
Denmark	0.5	0	0	0.05	0	0.01	0.39	0.04	0.01
Estonia	0	0.23	0.08	0	0.16	0.01	0.01	0.03	0.48
Finland	0	0.11	0.31	0	0.01	0	0	0.07	0.5
Germany	0.23	0	0	0.04	0	0.03	0.67	0.01	0.01
Latvia	0	0.04	0.01	0	0.81	0.05	0.07	0.01	0.01
Lithuania	0.01	0	0	0	0.02	0.58	0.33	0.01	0.05
Poland	0.02	0	0	0	0	0.04	0.91	0.01	0.02
Sweden	0.17	0.01	0.12	0.02	0.02	0.07	0.4	0.18	0.03
Russia	0	0.05	0.02	0	0	0.04	0.43	0	0.46

Comparison of the Tables reveals how differently the two pollutants are carried in the Baltic Sea. Moreover, countries differ from each other significantly in terms of the proportion of their effluents that remains within their own coastal zone. In some countries, such as Latvia, Poland and Denmark, large parts of effluents remain in their own coastal zones, while others, such as Estonia, Germany, Sweden and Finland, the larger part of effluents end up in other countries' coastal zones.

Given the national loads of nitrogen and phosphorus, we can solve for their aggregate concentration in the water areas of each country by applying the transfer coefficients given in Tables 1 and 2. Loads and concentrations are given in Table 3. The second (third) column gives the national levels of nitrogen (phosphorus) effluents for the base year of our calculations 1990, which is close enough to the 50% reduction announcement year 1988. The fourth and fifth columns give their country-based concentrations. Recall that one country may locate in many sub-regions of the Baltic Sea. For instance, Sweden potentially suffers quite a lot from nitrogen concentration, but it is distributed in 5 sub-regions. The sixth and seventh columns indicate how great the foreign share of the load is in absolute terms for each country. The ratio of domestic versus foreign pollution in each country seems to vary a lot. While more than half of the nitrogen concentration to Germany, Estonia, and Denmark come from abroad, Poland, Latvia and Finland are themselves responsible for the larger part of their nitrogen concentration. For phosphorus, Denmark, Germany, Sweden and Russia receive more than half of their concentrations from abroad, whereas Latvia, Poland and Finland produce most of their concentrations themselves.

Table 3. Nitrogen and phosphorus loads and concentrations for 1990 in tonnes

	Effluents 1990		Load 1990		Load from Other countries	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Denmark	71800	5754	100464	5021	56666	2144
Estonia	49483	1075	22827	1428	12931	1180
Finland	73069	5153	40326	2322	16213	724
Germany	58025	3717	19065	508	13843	359
Latvia	20569	3880	37307	3529	19824	386
Lithuania	72455	4527	69365	4857	25892	2231
Poland	304469	31707	413670	40432	145737	11579
Russia	106049	8447	108166	8080	60444	4194
Sweden	108408	3589	50710	1707	23608	1061
In total	864327	67849	861901	67884	375158	23860

3.2 Abatement Costs of Nitrogen and Phosphorus

We follow the conventional way of approximating abatement costs by postulating a quadratic form for the total abatement costs, and then estimate the sizes of relevant parameters from the abatement data available. Hence, the abatement costs of nitrogen and (by changing the symbol *n* to *p*) phosphorus are quadratic as follows

[8] $$c_i(n_1) = \gamma_i (n_i^0 - n_i)^2 + \varepsilon_i (n_i^0 - n_i) + \mu_i \qquad i = 1...9$$

where the superscript 0 refers to the initial level of pollution.

The data for nitrogen and phosphorus abatement costs are compiled by Helcom according to cost estimates provided by the national authorities. We used all available data, including both the pre-feasibility studies of abatement projects in current and deleted hot spots, as well as data on actual investments and effluent reductions. We developed a step function for abatement costs, to which we have fitted equation (8) by assuming that the cheapest investments have been made first. Since HELCOM data deals with separate years, we have calculated the costs and reductions on an annual basis. To do this, we have had to assume something about the amortization of investments. We assumed that investments are paid within a ten-year period; obviously, longer amortization times would have the effect of lowering our cost estimates.[4]

Table 4 presents the estimated parameter values of the abatement cost functions and the levels of marginal costs at the 50% reduction level. In the table, we have emphasized figures for those countries that face the highest marginal costs. Generally, the unit costs for the cheapest investments are an order of magnitude lower in the Baltic countries, in Poland, and in Russia, than they are in the Nordic countries and in Germany. The costs also appear highly non-linear in most of the countries, particularly in the Nordic countries.[5] The highest and lowest unit costs for the littoral countries as well as graphical examples of cost functions for some countries are given in the Appendix.

Table 4. Estimated Abatement Cost Parameters

	Nitrogen			Phosphorus		
	ε	γ	MC in euros	ε	γ	MC in euros
Denmark	4.31E-05	4.00E-07	28763	0.001033	1.48E-06	9549
Estonia	1.15E-05	1.72E-05	**851136**	8.81E-05	1.17E-06	**157096**
Finland	2.83E-09	6.67E-06	**487377**	2.21e-08	0.000898	**2647350**
Germany	2.62E-05	6.67E-06	**1073507**	1.26E-07	0.000224	**832832**
Latvia	6.79E-06	1.85E-05	424	4.84E-09	1.54E-05	**202216**
Lithuania	2.43E-05	2.03E-08	55381	1.00E-05	9.89E-06	44790
Poland	5.71E-05	7.64E-07	30809	2.33E-06	1.03E-06	43217
Russia	2.33E-08	1.90E-05	**2014950**	7.50E-06	4.38E-06	36333
Sweden	0.000708	4.23E-06	**457751**	5.75E-07	0.000848	**3044320**

While the HELCOM data is fairly comprehensive, there are major drawbacks in the data as well. Thus, we have been able to base our cost estimates on actual investment data for all other countries save Denmark. In her case, we have had to resort to pre-feasibility studies on abatement projects. However, even in the case of the other countries, the data only gives us information on actual investments and the changes in effluents. It is impossible to determine the extent to which abatement has been the cause for load reductions instead of the economic down-turn in many of the countries.[6] Conversely, in many countries significant investments in abatement appear to have failed in reducing loads, no doubt because of economic growth.

But while the data is by no means as reliable as we would like it to be, it does have the advantage of having been acknowledged by all countries. Moreover, uncertainties concerning the exact level and shape of the cost functions – as well as the accuracy of county-based load information -- will be identical from country to country in our models so that despite uncertainties, comparison of the results is entirely meaningful.

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4 However, since all countries are treated in a similar fashion, their meaningful comparison is not hindered by this essentially arbitrary assumption.

5 The non-linearity may be due to the nature of the investment projects. In Sweden and Finland many of the (now deleted) hot spots involved process industries, where large investments apparently only produced small reductions in emissions, no doubt because they were connected to increases in production, whereas in the Baltic countries and in Russia, hot spots have had more to do with municipal waste treatment that probably has been taken care of already earlier on in the Nordic countries.

6 With a reference to Kyoto process, we could perhaps call this a problem of "hot water".

4 RESULTS OF SIMULATIONS: CLUB VERSUS COST-EFFICIENT SOLUTION FOR NUTRIENTS

Given the information on the loads of both nutrients and of the concentration of nitrogen we can solve for the non-cooperative and cooperative solutions and for the 50% club solution, when the base year is 1990. The estimated solutions allow us to discuss the development and country-based abatement strategies since 1990. Furthermore, they enable us to outline some possible future implementation strategies.

4.1 The Club 50% Solution for Nitrogen and Phosphorus

In the club solution all countries reduce their nutrient loads by 50% irrespective of the relative efficiency of money used for abatement in the home country versus a neighbor country. Table 5 shows for nitrogen the country-based and over-all load reductions in tonnes, the abatement costs required in millions of euros, and the resulting concentration of nitrogen in tonnes.

Table 5. Club solution for nitrogen: abatement costs and concentrations

	Effluents	Nitrogen load	Effluent	Abatement	Nitrogen
	for 1990 (tonnes)	For 1990 (tonnes)	Reduction (tonnes/a)	Costs (m euros)	Load (tonnes/a)
Denmark	71800	99369	35900	517	49685
Estonia	49483	22782	24742	10529	11391
Finland	73069	40007	36535	8903	20003
Germany	58025	18883	29013	15573	9441
Latvia	20569	37171	10285	2	18585
Lithuania	72455	69137	36228	1004	34569
Poland	304469	412302	152235	2349	206151
Russia	106049	108121	53025	53420	54060
Sweden	103848	49570	51924	11441	24785
In total	859767	857341	429884	103739	428670

The most striking feature of the club solution is the huge difference in abatement costs. These costs vary from 2 millions up to 53420 million euros, i.e., the difference is of order 2500. The greatest abatement costs accrue to Russia, Germany and Sweden, whereas the benefits in terms of aggregate nitrogen reduction are the same across all countries. Hence, one might conclude that high marginal cost countries such as Finland, Germany and Sweden, as well as the lower marginal cost country Russia would have incentives not to follow the agreement.

Table 6 gives the respective solution for phosphorus in terms of abatement costs and concentrations.

Table 6. Club solution for phosphorus: abatement costs and concentrations

	Effluents for 1990 (tonnes)	Phosphorus load for 1990 (tonnes)	Effluent Reduction (tonnes/a)	Abatement Costs (m. euros)	Phosphorus Load (tonnes/a)
Denmark	5754	7302	2877	15	3651
Estonia	1075	1428	538	42	714
Finland	5153	2322	2577	3421	1161
Germany	3717	508	1859	774	254
Latvia	3880	3529	1940	196	1764
Lithuania	4527	4857	2264	51	2428
Poland	31707	40432	15854	343	20216
Russia	8447	8080	4224	77	4040
Sweden	3589	1707	1795	2731	854
In total	67849	70164	33925	7650	35082

For phosphorus, the difference between the highest and lowest costs is smaller, yet significant. The lowest costs are 15 million euros for Denmark, while they are 3421 million euros for Finland, i.e. the difference is of order 200. In the club solution, the greatest abatement costs accrue to Finland, Sweden and Germany. Thus these countries might have incentives not to follow the agreement.

4.2 The Cost-Efficient Agreement for 50% Reduction

In the cost-efficient solution the countries minimize the sum of the costs of nutrient abatement subject to the requirement that the aggregate load is reduced by 50%. The results for cost-efficient solutions supplemented with estimates of overall concentrations are shown Tables 7 and 8.

Table 7. Cost-Efficient solution for nitrogen: abatement costs and concentration

	Effluents for 1990 (tonnes)	Nitrogen load for 1990 (tonnes)	Effluent Reduction (tonnes/a)	Abatement Costs (in euros)	Nitrogen Load (tonnes/a)
Denmark	71800	99369	57440	4	48980
Estonia	49483	22782	5752	569	19032
Finland	73069	40007	14834	1468	32691
Germany	58025	18883	5348	529	9864
Latvia	20569	37171	16455	6	19016
Lithuania	72455	69137	57964	2568	21957
Poland	304469	412302	243575	6006	154737
Russia	106049	108121	5207	515	92528
Sweden	103848	49570	23308	2314	31728
In total	859767	857341	429884	13979	430533

As Table 7 indicates, the cost-efficient solution brings the same overall reduction in nitrogen emissions and roughly the same aggregate concentrations as the club solution. The distribution of reductions and abatement costs across countries, however, differs considerably from those of the club solution, as do the overall abatement costs. In this case the cost difference is much smaller, of order 1500, between the smallest (Denmark) and greatest (Poland). The greatest reduction of effluents accrue to Poland, Lithuania, Denmark and Sweden, whereas Poland, Lithuania, Sweden and Finland have the greatest abatement costs. Poland, Lithuania, and Denmark seem to be the greatest beneficiaries – the aggregate nitrogen concentration decreases by more than 50% for these countries. Germany and Latvia, on the other hand, get almost as large reductions of nitrogen concentrations but for much smaller costs. Sweden gets a large reduction but at a high cost, whereas Finland faces high costs but manages only a small reduction of concentrations.

The cost-efficient solution for phosphorus is shown in Table 8.

Table 8. Cost-Efficient solution for phosphorus: abatement costs and concentrations

	Effluents	Phosphorus load	Effluent	Abatement	Phosphorus
	for 1990 (tonnes)	for 1990 (toness)	Reduction (tonnes/a)	Costs (m. euros)	Load (tonnes/a)
Denmark	5754	7302	4603	36	2877
Estonia	1075	1428	182	5	1050
Finland	5153	2322	44	1	2161
Germany	3717	508	119	3	273
Latvia	3880	3529	510	14	3031
Lithuania	4527	4857	2693	72	2186
Poland	31707	40432	19545	521	17168
Russia	8447	8080	6197	165	4541
Sweden	3589	1707	31	1	1280
In total	67849	70164	33925	818	34567

In this case the greatest reductions in effluents accrue to Poland, Russia and Lithuania. These countries also face the greatest abatement costs as well as greatest reductions in concentrations. Denmark, Germany and Estonia, on the other hand, get large reductions of phosphorus concentrations for little cost.

4.3 Comparing Cost-efficient and Club Solutions

We have condensed our main results into Tables 9 and 10 in order to compare the club solution with the cost-efficient solution. The third column shows the load reduction across countries under 50% declaration, and fourth column shows the cost-efficient solution. Both solutions result in the same overall reduction in tonnes, but the reductions between countries will differ. The fifth and sixth columns indicate the resulting abatement costs between countries in millions of euros.

Our most important finding in Tables 9 and 10 concerns the overall costs of nitrogen abatement. In the cost-efficient solution, the nitrogen abatement costs are 8-10 times higher in the club-solution than in the cost-efficient solution. Likewise, phosphorus abatement costs are three times higher in the club solution. Hence, club-agreements are an expensive way of achieving the joint reduction target.[7] Moreover, our cost estimates clearly exceed

[7] Our results for nitrogen, as well as for phosphorus, are conformed by the findings in Gren et. al. 2000.

the cost estimates of the Baltic Sea Environmental Joint Comprehensive Action Programme (18 billion euros in total), whereas the cost-efficient solutions give costs that are within those budgeted in the Program.

Table 9. Club versus cost-efficient solutions: Nitrogen

	Effluents	Club reduction	Cost-efficient	Abatement costs in	Abatement costs in
	for 1990	of effluents	Abatement	club-solution	cost-efficient solution
Denmark	71800	35900	57440	517	1322
Estonia	49483	24742	5993	10529	618
Finland	73069	36535	15455	8903	1593
Germany	58025	29013	5571	15573	574
Latvia	20569	10285	16455	2	6
Lithuania	72455	36228	57964	1004	2568
Poland	304469	152235	243575	2349	6006
Russia	106049	53025	5425	53420	559
Sweden	108408	54204	24285	12466	2512
In total	864327	432164	432164	104764	15759

Table 10. Club versus cost-efficient solutions: Phosphorus

	Effluents	Club reduction	Cost-efficient	Abatement costs in	Abatement costs in
	in 1990	of effluents	Abatement	club-solution	cost-efficient solution
Denmark	5754	2877	4603	15	36
Estonia	1075	538	182	42	5
Finland	5153	2577	44	3421	1
Germany	3717	1859	119	774	3
Latvia	3880	1940	510	196	14
Lithuania	4527	2264	2693	51	72
Poland	31707	15854	19545	343	521
Russia	8447	4224	6197	77	165
Sweden	3589	1795	31	2731	1
In total	67849	33925	33925	7650	818

Finland and Sweden are good examples of countries that could contribute more cost-efficiently to the overall phosphorus target by supporting actions in other countries. Furthermore, in view of the data in Tables 7 and 8, they would not see much of the benefits of their contributions abroad but this is misleading. Moving to the sub-region level would clearly show that in the case of the Gulf of Finland, Finland would benefit very much from load reductions in Russia and Sweden from load reductions in the Southern Baltic Sea. In contrast, Russia would benefit herself from her own efforts. Likewise, Finland could improve the quality of water in the Archipelago Sea by solely domestic activities.

They found the difference was even greater that we did, which is partly explained by the fact that they use a more recent data and include wetlands as filter for nutrients.

We indicated earlier that, in the case of nitrogen, the high marginal abatement cost countries Finland, Germany and Sweden, as well as, the low marginal cost country Russia may have incentives not to follow the agreement. In the case of phosphorus Finland, Sweden and Germany have incentives not to follow the declaration. How does the empirical data support our speculations? The 1995 situation for nitrogen is shown in Table 11.

Table 11. Nitrogen loads in 1990 and 1995

	Effluents for 1990 tonnes	Effluents for 1995 tonnes	Reduction 1990-1995 tonnes	Club reduction tonnes	Remaining obligation tonnes
Denmark	71800	54834	16966	35900	18934
Estonia	49483	17372	32111	24742	-7370
Finland	73069	60688	12381	36535	24154
Germany	58025	40830	17195	29013	11818
Latvia	20569	5158	15411	10285	-5127
Lithuania	72455	43293	29162	36228	7066
Poland	304469	228801	75668	152235	76567
Russia	106049	50327	55722	53025	-2698
Sweden	108408	87860	20548	54204	33656
In total	864327	589163	275164	432164	157000

Notably, Estonia, Latvia and Russia seem to have achieved the target reduction, whereas the progress for other countries has been slower. In general, some 30% of the aggregate reduction obligation remains to be achieved. In the light of our abatement investment cost data, the reductions in Estonia, Latvia and Russia result mainly from their economic slowdown rather than through an active environmental policy. In terms of magnitudes, Finland's, Germany's and Sweden's reductions are the most modest. Hence, our hypotheses concerning their incentives seem to hold.

The 1995 situation concerning phosphorus is shown in Table 12.

Table 12. Phosphorus load in 1990-1995

	Effluents for 1990 tonnes	Effluents for 1995 tonnes	Reduction 1990-1995 tonnes	Club reduction tonnes	Remaining obligation tonnes
Denmark	5754	1960	3794	2877	-917
Estonia	1075	545	530	538	8
Finland	5153	4292	861	2577	1716
Germany	3717	1365	2352	1859	-494
Latvia	3880	1089	2791	1940	-851
Lithuania	4527	2014	2513	2264	-250
Poland	31707	19904	11803	15854	4051
Russia	8447	4643	3804	4224	420
Sweden	3589	1657	1932	1795	-138
In total	67849	37469	30380	33925	3545

All countries except Finland, Poland and Russia have achieved the reduction obligation. In fact, many countries reduced phosphorus leaching by more than the 50% reduction would have required. Therefore, our speculations seem to hold only for Finland. The fact that

Poland and Russia have not fulfilled the agreement probably is due to the lack of financial resources. On the whole, the cheaper abatement costs of phosphorus explain why most countries have indeed fulfilled the agreement.

Finally, the club solution has an undesirable asymmetry property for the Baltic Sea countries. Those countries, for which reductions of nutrients are cheapest, do not have funds for environmental investments, while those countries, for which reductions are most expensive, do have funds for environmental investments. It is evident that the best way of minimizing the joint costs of abating the Baltic Sea would be to direct investment funds to those targets, which yield the highest reductions in nutrients. Therefore, one would like to ask: Are there means of fine tuning current policy towards cost-efficiency? In the next section we show that there clearly are. Such a procedure is joint implementation policy.

5 JOINT IMPLEMENTATION

Suppose that the littoral countries decide to adopt a joint implementation policy. This would allow those countries that have high abatement costs to achieve part of their abatement commitment in other countries, where abatement costs are lower.[8] Hence, the abatement policy would move towards the cost-efficient solution. Joint implementation is a feasible option provided that the cost savings of the high-cost countries suffice to cover the increased costs in low-cost countries. The potential for cost savings can be assessed easily by comparing abatement costs in the two solutions.

Table 13. Abatement and abatement costs millions euros: Nitrogen

	Club reduction	Efficient reduction	Reduction 1990-1995	Club costs	Efficient costs	Estimated costs	Club costs – Efficient costs	Estimated costs – Efficient costs
Denmark	**35900**	**57440**	**16966**	**517**	**1322**	**116**	**-805**	**-1206**
Estonia	24742	5993	32111	10529	617	17736	9912	17119
Finland	**36535**	**15455**	**12381**	**8903**	**1593**	**1022**	**7310**	**-571**
Germany	**29013**	**5571**	**17195**	**15573**	**574**	**5470**	**14999**	**4896**
Latvia	10285	16455	15410	2	5	5	-3	0
Lithuania	**36228**	**57964**	**29162**	**1004**	**2568**	**650**	**-1564**	**-1918**
Poland	**152235**	**243575**	**75668**	**2349**	**6006**	**583**	**-3657**	**-5423**
Russia	53025	5425	55722	53420	559	58994	52861	58435
Sweden	**54204**	**24285**	**20548**	**12466**	**2511**	**1801**	**9955**	**-710**
In total	432164	432164	275163	104764	15755	86377	89009	70622

[8] Note that in the joint implementation, each potentially investing country chooses the investment targets not only on the merit of reduction achieved by the investments, but also on the basis of the improvement in the quality of water in her coastal waters. This latter aspect in joint implementation brings some ecological sensibility to the joint abatement solution. For instance, based of the estimated transfer coefficients we can guess that Finland might be interested in investing in Russia and Estonia so as to improve the water quality in the Gulf of Finland. Germany, Denmark and Sweden in turn would like to invest in Poland and possibly in Latvia and Lithuania so as to improve water quality in the Southern parts of the Baltic Sea.

The estimated reduction costs (in millions euros) for nitrogen in both the club and the cost-efficient solutions – labeled “Club costs” and “Efficient costs”, respectively are shown in Table 13. The column labeled “Estimated costs” refers to the estimated costs of achieving the reductions in 1990-95. The next column gives the difference in abatement costs between the two solutions. Finally, the last column indicates the potential benefits of joint implementation as a difference between the costs of the cost-efficient solution and costs paid so far. Negative entries signify increased abatement in the country in question, whereas positive entries indicate lower abatement costs.

Looking at the column “club costs – efficient costs” clearly indicates that the potential for cost savings is very significant indeed, amounting to almost 90 billion euros. Thus high-cost countries – principally Finland, Sweden and Germany – would be more than able to finance increased abatement in low-cost countries – Denmark, Latvia, Lithuania and Poland. We can also argue the case for joint implementation in the light of actual effluents after 1990. Recall from Table 7 that Estonia, Latvia and Russia had reduced their effluents below the level specified by the Baltic Sea agreement, whereas all other littoral countries had yet to meet the commitment in 1995. We have emphasized the figures for those countries that were in non-compliance of their reduction target in 1995. The remaining reduction amounts to some 157 000 tonnes, more than a third of the club target. Evidently, those countries that are already in compliance have nothing to gain from joint implementation. The remaining countries, however, would have to face additional costs to reach their commitment level. These costs are very high for Germany, whose cost savings would obviously more than cover the increased investment in abatement in Denmark, Lithuania and Poland. This is evident from the figures in the column “Estimated costs – efficient costs”.

The cost estimates and effluent data for phosphorus are given in Table 14. Comparing the costs under club and cost-efficient solutions, it is clear that even in the case of phosphorus abatement, the potential for cost savings is very large.

Table 14. Abatement and abatement costs millions euros: Phosphorus

	Club reduction	Efficient reduction	Reduction 1990-1995	Club costs	Efficient costs	Estimated costs	Club costs – Efficient costs	Estimated costs – Efficient costs
Denmark	2877	4603	3794	15	36	25	-21	-11
Estonia	538	182	530	42	4	41	38	37
Finland	**2577**	**44**	**861**	**3421**	**1**	**387**	**3420**	**386**
Germany	1859	119	2352	774	3	1239	771	1236
Latvia	1940	510	2791	196	13	406	183	393
Lithuania	2264	2693	2513	51	71	63	-20	-8
Poland	**15854**	**19545**	**11803**	**343**	**521**	**191**	**-178**	**-330**
Russia	**4224**	**6197**	**3804**	**77**	**165**	**62**	**-88**	**-103**
Sweden	1795	31	1932	2731	0	3165	2731	3165
In total	33925	33925	30380	7650	814	5579	6836	4765

Based on the 1990 situation, high-cost countries – Finland, Sweden and Germany – would definitely benefit from joint implementation. However, by 1995, most countries had already achieved or exceeded the reduction target of the club-agreement. Only Finland, Poland and Russia had still to attain compliance. But the case for joint implementation is still there, because Finnish cost savings nearly cover the combined Polish and Russian abatement costs.

6 CONCLUSIONS: WHAT CAN BE LEARNED?

Our environmental economic analysis has clearly demonstrated that a general 50% reduction of nutrient loads across all participating countries is very expensive when compared with a cost-efficient solution. This is an undesirable feature, because with the costs associated to the common 50% reduction the participating countries could afford a much better water quality in the Baltic Sea. Hence, lesson number one in executing the ministerial 50% declaration is an adaptation of a much more flexible implementation policy than the declaration would suggest. A flexible implementation policy should reflect more adequately the cost differences between the participating countries. We have demonstrated that an excellent way of moving towards a cost-efficient solution is the mechanism of joint implementation. There are many countries, which could benefit from joint implementation in the reduction of nitrogen. There also seems still be some scope for joint implementation in abating the phosphorus load.

There are two issues to further modify this lesson. First, a common 50% reduction for all countries is very insensitive to the respective abatement histories of participating countries. The cost-efficiency principle, which leads to an outcome where countries that have the lowest abatement costs reduce their nutrient load more, takes this only partly into account. The second modifier is much more important. A common 50% reduction for both nutrients seems to be an inefficient way to reduce algae blooms. The fact that in most sub-regions of the Baltic Sea the nitrogen load is the critical limiting factor in algae blooming would suggest that better water quality could be achieved by putting more weight on nitrogen reduction in these regions. On the other hand, in the Gulf on Bothnia and in the Gulf of Riga, it would be more favorable to reduce phosphorus considerably more than nitrogen. These observations can be easily taken into account in implementing the declaration. For instance, the policy towards hot spots could reflect these considerations.

It is more than evident that reliable data basis is needed, which also comprises of relevant variables from the viewpoint of economic analysis. Most importantly, policy planning and implementation requires good information about two things. First, good estimates for country-based abatement cost functions are necessary for the implementation policy. Second, an ecological description of the flow of nutrients across, and algae growth in the sub-regions of the Baltic Sea is an absolute necessity for the successful fine tuning of nutrient load reduction policy. In these respects there remains much to be done, including cooperation between environmental economists and marine biologists.

Given that for phosphorus the target has been achieved and we need new measures for more sensitive nitrogen policy, planning of the second-phase ecologically sensitive and diversified policy will soon be on the agenda. The planning of an environmentally sensitive policy, requires that the transfer of nitrogen and phosphorus and their roles in the eutrophication in various sub-regions of the Baltic Sea be explicitly taken into account. The approach of joint implementation presented in this paper, as well as, permit trading (if found useful by the contracting Helcom countries) can easily be tailored to match these requirements. This might be a good time to start the necessary background planning.

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Appendix. Abatement costs in the Baltic Sea countries

This Appendix describes our procedures for estimating the abatement cost functions. Our estimates are based on HELCOM data on abatement costs and effluents in the Baltic Sea countries. This data are compiled by Helcom according to the figures provided by the national authorities. The data allows us to link nutrient reductions to abatement costs in each of the Baltic Sea countries.

The original HELCOM data are reported in several Helcom publications, the most important of these being the yearly Activity reports covering activities in and effluents from all hot spots. For some countries, many of the original hot spots have been deleted from the list on the strength of realized abatement goals, in which case the realized investments should have been reported in the Activity reports. Where necessary, we have also considered the 1993 Pre-feasibility studies for actions then considered necessary in these hot spots, which also contains estimated costs for these actions. In the end, we have had to rely on pre-feasibility studies only in the case of Denmark, while actual investment costs are not given in the Activity reports.

The Helcom data has the great advantage of being recognized by all the member states; yet it has major shortcomings as well. Thus, only a small part of the realized effluent reductions can be linked to abatement investments on the strength of the data. There are several reasons for this. First, in many cases there have been no investments at all, yet effluent reductions have occurred. This is presumably a consequence of an economic down turn or a related reason. Conversely, there are numerous cases where investments have been quite significant but effluents nevertheless have increased. Data on investments may naturally also be missing altogether. We also feel that the hot-spot data may give an upward-biased estimate of the overall costs of abatement, because it covers only those effluent sources that have been deemed as most crucial for the protection of the Baltic Sea. However, abatement has most likely taken place in other point sources as well, without it having been reported to Helcom at all. Since these less urgent sources have not made it to the list of hot spots, it is reasonable to take them to be cheaper than the hot spots. We have tried to cope with these problems by including only those observations that contain information on both effluents and abatement investments. This has reduced the available observations drastically from close to nine hundred to less than a hundred for both nitrogen and phosphorus. Thus it is clear that the data gives an incomplete picture of the true costs of abatement. Nevertheless, even with its shortcomings the Helcom data probably represent the best uniform collection of effluent and abatement cost data for the Baltic Sea.

We have calculated unit abatement costs for both phosphorus and nitrogen using all available Helcom data. We then assume that in each country, the cheapest investments are the first to have been made. Arranging the data accordingly, we can present realized abatement investments and effluent reductions for each country in the form of cost curves, which we then have approximated with a quadratic cost function. Naturally, these estimated cost curves suffer from the shortcomings of the data, most importantly from the small number of observations and the incomplete coverage of the Helcom data.

Tables 1 and 2 reports the cheapest and the costliest projects for each country in our data with the exception of Denmark, for which only the Pre-Feasibility studies were available. The truly low-cost abatement investments have been made either in the management of wetlands, agricultural runoffs or municipal wastes or in apparently outdated industrial sites, whereas highest costs almost always stem from industrial hot spots where cheap measures most likely have already been taken.

Table 1. Smallest and largest unit costs for nitrogen abatement

Country	*Type*	*Unit cost, euro/a*
Estonia/min	Coastal Lagoon/Wetland/Management programme	6
Estonia/max	Coastal Lagoon/Wetland/Management programme	720000
Finland/min	Agricultural Runoff	7154
Finland/max	Industry (Pulp&paper)	15000000
Germany/min	Municipal&Industrial	31342
Germany/max	Municipal&Industrial	953333
Latvia/min	Industry (Pulp&paper)	106
Latvia/max	Municipal&Industrial	671739
Lithuania/min	Industry (Fertilizer)	193
Lithuania/max	Municipal&Industrial	1150000
Poland/min	Municipal&Industrial	2072
Poland/max	Municipal&Industrial	3111111
Russia/min	Industry (Pulp&paper)	1042
Russia/max	Industry (Aluminium)	80556
Sweden/min	Industry (Pulp&paper)	38291
Sweden/max	Industry (Pulp&paper)	1833333

Table 2. Smallest and largest unit costs for phosphorus abatement

Country	*Type*	*Unit cost, euro/a*
Estonia/min	Coastal Lagoon/Wetland/Management programme	60
Estonia/max	Area municipal&industrial	3180000
Finland/min	Agricultural Runoff	80000
Finland/max	Industry (Pulp&paper)	23000000
Germany/min	Municipal&Industrial	98010
Germany/max	Municipal&Industrial	45000000
Latvia/min	Industry (Pulp&paper)	1786
Latvia/max	Agricultural Runoff programme	90000
Lith/Russia	Coastal Lagoon/Wetland/Management programme	640
Lithuania/min	Municipal&Industrial	4121
Lithuania/max	Municipal	1600000
Poland/min	Municipal&Industrial	526
Poland/max	Municipal&Industrial	16825000
Russia/min	Municipal	1402
Russia/max	Municipal	20550000
Sweden/min	Industry (Pulp&paper)	66892
Sweden/max	Industry (Pulp&paper)	8333333

Examples of the cost curves based on the Activity reports are reported in Figures 1 to 6. They merit two general comments. First, for both nitrogen and phosphorus, the costs appear to rise strikingly fast with the amounts of effluents reduced in all countries. This may to an extent reflect the afore-mentioned problems of the Helcom data. Second, the lowest unit costs for Poland, and Russia are at close to an order of magnitude lower than the lowest unit costs for Finland, Germany and Sweden; for the Baltic countries, the difference is two orders of magnitude. The low-cost abatement projects have also tended to yield larger effluent reductions in Poland and the Baltic countries than single projects in the Nordic countries and Germany have.

Figure 1. Nitrogen abatement unit costs in Finland.

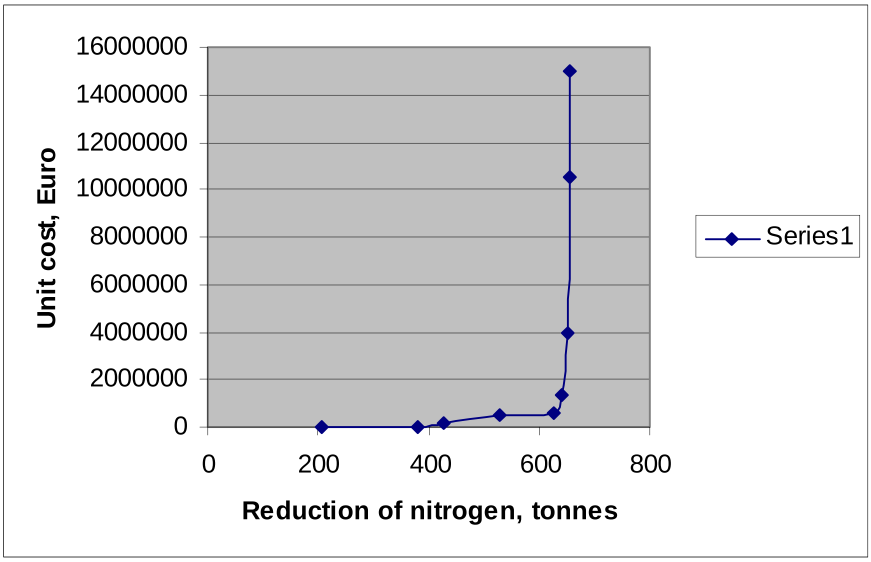


Figure 2. Nitrogen abatement unit costs in Germany.

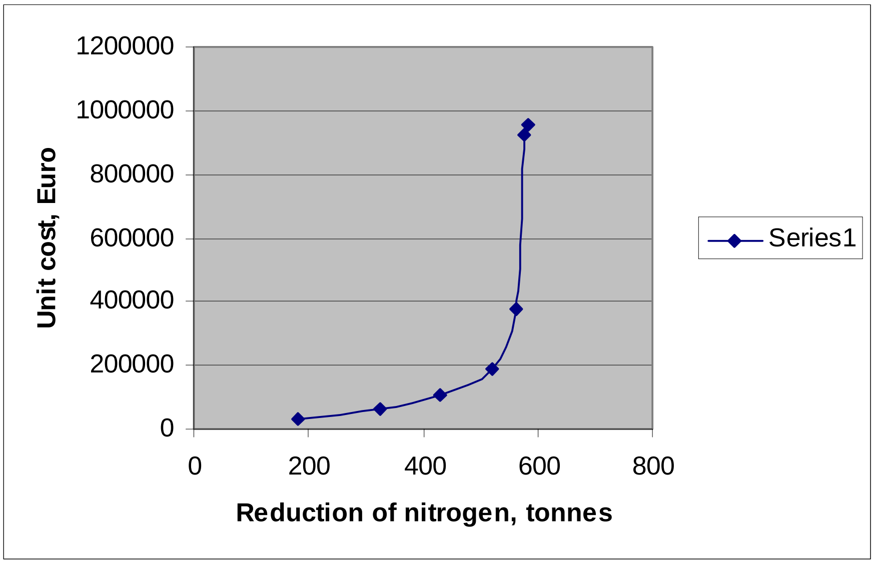


Figure 3. Nitrogen abatement unit costs in Lithuania.

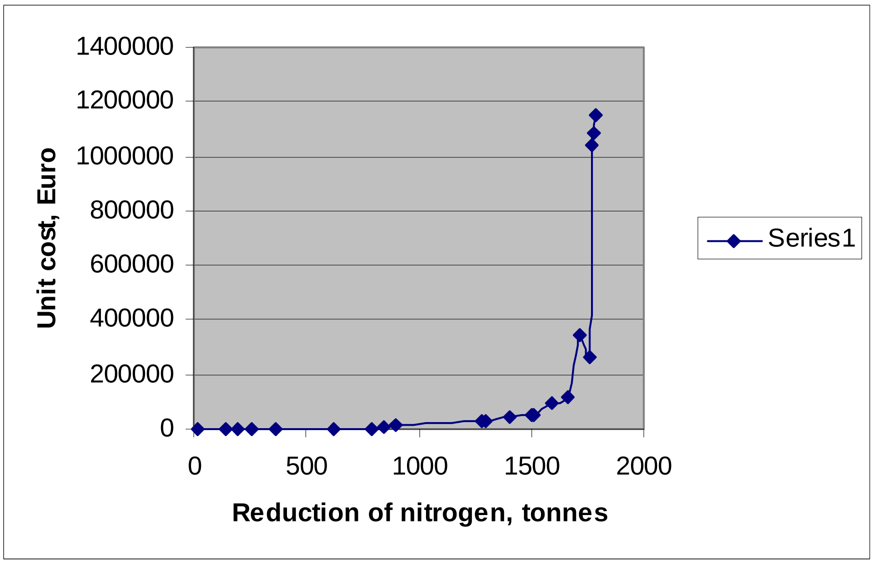


Figure 4. Nitrogen abatement unit costs in Poland.

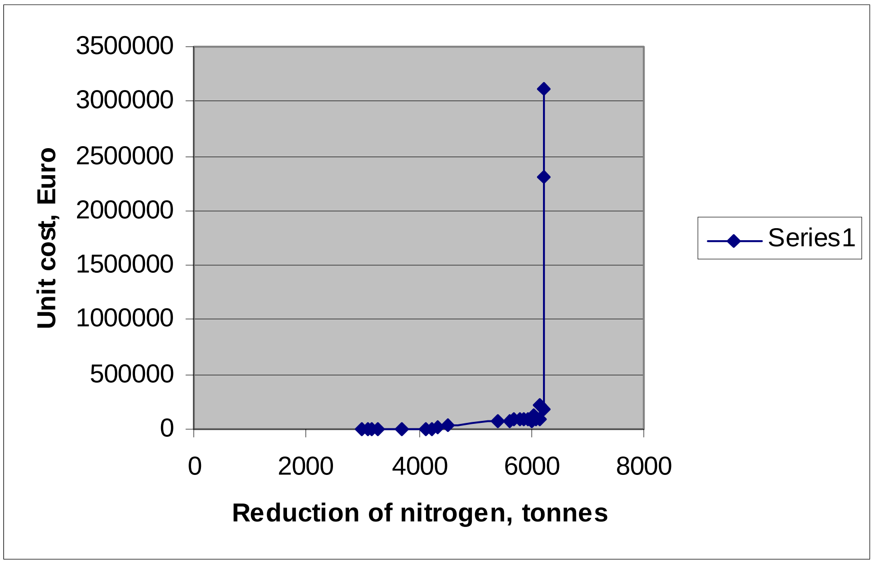


Figure 5. Phosphorus abatement unit costs in Finland.

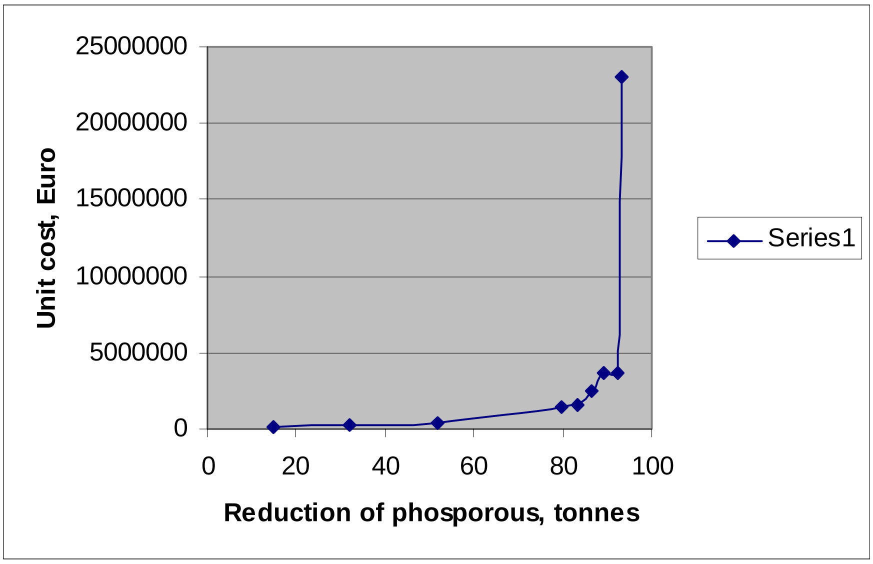


Figure 6. Phosphorus abatement unit costs in Germany.

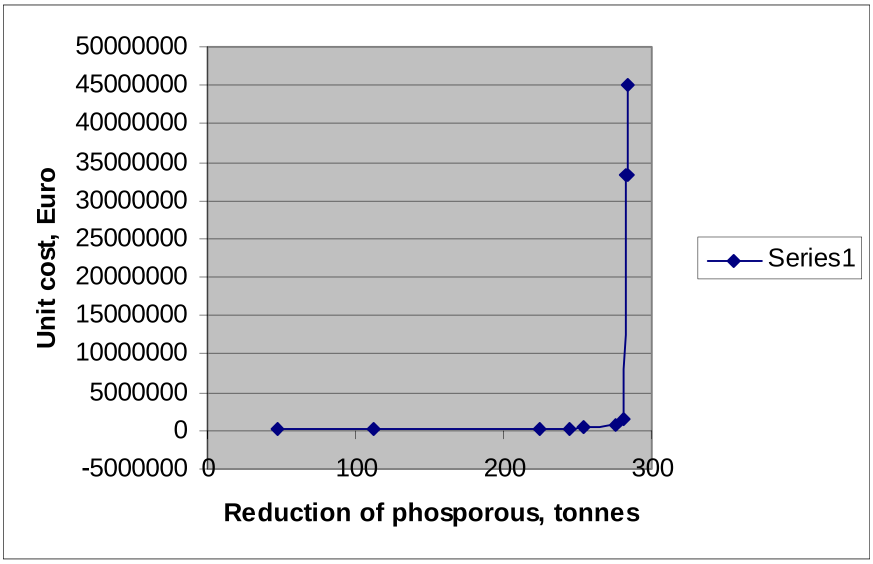


Figure 7. Phosphorus abatement unit costs in Lithuania.

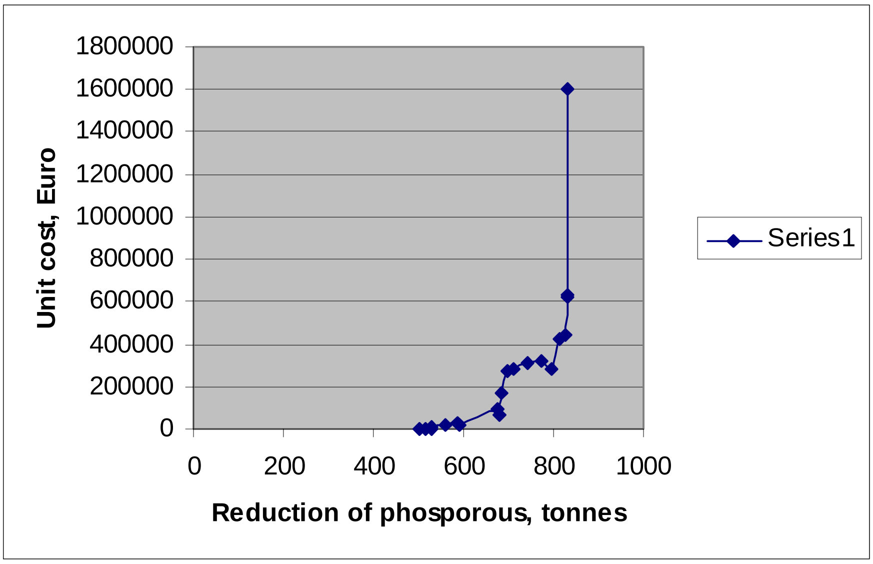
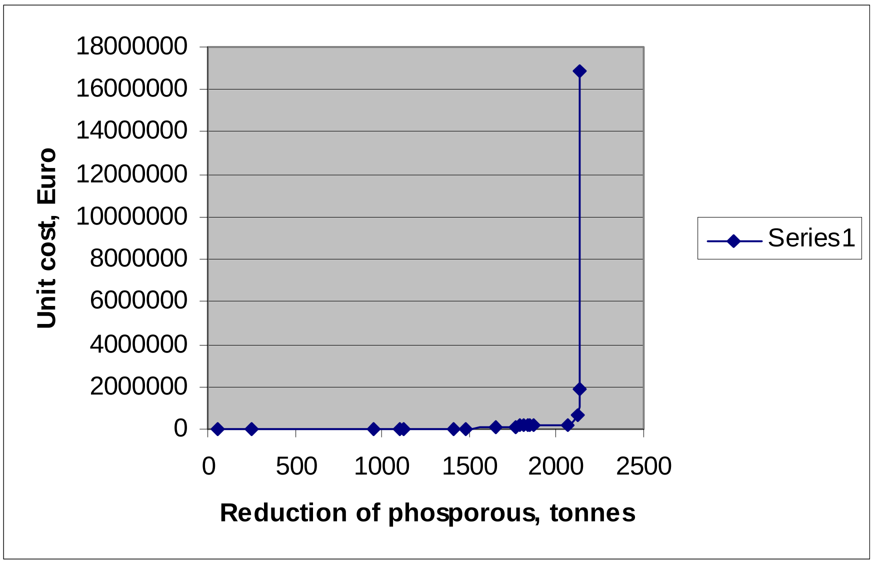


Figure 8. Phosphorus abatement unit costs in Poland.



Hot Spots in Finland

The Finnish hot spot data is given in tables 10 and 11. Note first that most of the Finnish hot spots have already been deleted from the list. Second, the remaining hot spots have mostly to do with agricultural and municipal wastes. Finally, the remaining hot spots are located in the areas in need of most urgent attention from the Finnish point of view, the Archipelago and the Gulf of Finland.

Table 3. Finnish hot spots for nitrogen

Status	Location	Type	Reduction t/a	Unit cost, euro/a
Active	Archipelago Sea	Agricultural Runoff	205	7154
Deleted	Lake Saimaa	Industry (Pulp&paper)	175	29333
Active	Lake Saimaa	Industry (Pulp&paper)	48	175694
Active	Gulf of Finland	Municipal	99	502778
Active	Gulf of Finland	Municipal	100	603333
Active	Bothnian Sea	Industry (Metal smelter)	13	1307692
Active	Bothnian Sea	Industry (Metal smelter)	13	3961538
Deleted	Bothnian Sea	Industry (Titanium oxide)	1	10500000
Deleted	Lake Saimaa	Industry (Pulp&paper)	1	15000000

Table 4. Finnish hot spots for phosphorus

Status	Location	Type	Reduction t/a	Unit cost, euro/a
Active	Archipelago Sea	Agricultural Runoff	15	80000
Deleted	Lake Saimaa	Industry (Pulp&paper)	16.85	249258
Deleted	Lake Saimaa	Industry (Pulp&paper)	20	345000
Active	Gulf of Finland	Municipal	28	1454464
Deleted	Bothnian Bay	Industry (Pulp&paper)	3.5	1523810
Deleted	Gulf of Finland	Industry (Pulp&paper)	3	2533333
Active	Bothnian Sea	Industry (Titanium oxide)	2.9	3620690
Active	Bothnian Sea	Industry (Titanium oxide)	2.9	3724138
Deleted	Lake Saimaa	Industry (Pulp&paper)	1	23000000

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