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Cost-effective nutrient and green-house gas management in the Baltic Sea region

Abstract

The authors analyze cost-effective multi-target management of nutrient and GHG emissions, the challenge of which arises from the multi-pollutant emission of several sources and multifunctional capacity of abatement measures. The simple theoretical analysis shows that simultaneous management of targets on both nutrients and GHG emission lower costs compared with separate management when 1) the same source emits more than one pollutant, and 2) measures are complements in pollutant abatement. The application to the Baltic Sea region, where countries face intergovernmental targets on nitrogen and phosphorus loads and on carbon emissions, shows that multi-target compared with separate target management can reduce total abatement costs by 11% or approximately 1.5 billion Euro, which corresponds to 0.1% of total GDP in the region. The main reasons for this gain are the consideration of effects on both carbon and nitrogen emissions from combustion of fossil fuels, and the optimal use of land use measures which affects carbon and nutrient sequestration. However, the gains are unevenly distributed among the riparian countries, where Poland makes the largest and Russia might even face a loss.

Keywords: cost-effectiveness, nutrients, green-house gas emission, pollutant sinks, the Baltic Sea.
JEL Classification: D99, O13, Q52, Q53, Q54.

Introduction

Both climate change and eutrophication are international environmental problems which have received much attention during the last decades, in particular climate change. The damages are caused by excessive emissions of carbon dioxides and carbon releases from soil due to conversion of forests into arable land (e.g. IPCC, 2014). Both these factors are also sources of eutrophication of coastal marine waters globally, which is caused by unbalanced and excessive loads of nutrients (e.g. Gilbert, 2007; Heisler et al., 2008). These create damages from eutrophication, such as increased frequency of harmful algal blooms, sea bottom areas without biological life, toxic cyanobacteria, and decreases in water transparency and populations of commercial fish species. Because of these common sources of damages, the simultaneous management of climate change and eutrophication may contribute to a lower cost than if managed in isolation. However, although this may be a consideration in practice by many policy makers there does not exist any cost-effectiveness analysis of the role of simultaneous management on a large scale management of both these problems. The purpose of this study is to calculate cost-effective management of simultaneous management of nutrient and GHG emissions for the Baltic Sea region, which has a long term experience of eutrophication management under the Helcom umbrella (Helcom, 2013) and of climate change management within the EU climate policies (Directive 2009/29/EC and Decision 406/2009/EC).

In principle, the purpose stated in this paper would be irrelevant if there were no dependency in emissions and/or abatement of the three pollutants nitrogen, phosphorus, and GHG. Then, cost-effective management of one of the pollutants would not affect the emissions of any of the other pollutants. We would argue that it is difficult to find any emission source or abatement measure that impacts only one of these pollutants. For example, combustion of fossil fuels generates emissions of CO_2, which affect the climate, and NO_X , which contribute to eutrophication. Similarly, livestock holdings result in releases of methane, one of the most damaging GHG, and emissions of nitrogen and phosphorus. Potential abatement measures include not only decreases in the use of these production factors, i.e. fossil fuels and livestock, but also creation of pollutant sinks which transform and store carbon and nutrient and thereby prevent pollutants from creating environmental damage. Thus, consideration of both climate and eutrophication targets is likely to lower total cost for reaching targets compared to when managed in isolation.

Although there exists a relatively large body of empirical literature on multi-pollutant management in economics, it is mainly applied to air pollution (e.g. Ammana et al., 2011) and considers specific technologies (e.g. Sun, 2014). Our study is therefore mostly related to two other strands of literature; cost-effective climate change and eutrophication management. The literature on climate change is large, where a majority of the studies calculate costs of GHG emission reduction at the national, international, or global scale (see Böhringer et al., 2009 for a review). The most common approach has been to use computable general equilibrium models. Another is the marginal abatement cost (MAC) approach, which does not consider all repercussions in the economy from decreases in energy use, but only the so-called first effects on the sectors directly affected by the decrease. The MAC approach has also been applied by most studies on cost-effective eutrophication management of the Baltic Sea, the literature of which is much smaller than that on climate change economics (Gren et al., 1997; Elofsson, 2006, 2007; Ollikainen and Hokatukla, 2001' Ahlvik and Pavlova, 2013). This study will also use the MAC approach for calculating costs of reductions in fossil fuels and nutrients. The main reason is the simplicity in the numerical calculation which is needed for integrating GHG and nutrient abatement measures and land use measures acting as pollutant sinks.

In our view, the main contribution of this study is the calculation of cost-effective attainment of targets on both GHG and nutrient emissions, and the inclusion of land use measures as pollutant sinks. To the best of our knowledge, this has not been made before at the international scale. Admittedly, the calculations rest on simple and static analysis on cost-effective allocation of multifunctional abatement measures, but add with respect to the empirical application on the Baltic Sea.

The study is organized as follows. Section 1 gives a simple model of cost-effective multi-target management. Section 2 provides data retrieval. Section 3 presents a cost-effective pollutant management. The final Section concludes the study.

1. A simple model of cost-effective multi-target management

The numerical model builds on the nutrient abatement model developed by Gren et al. (2008), but adds emission and abatement of GHG emissions. Since nutrient load into the Baltic Sea depends on climate and geo-hydrological condition which varies among drainage basins in the Baltic Sea, the entire catchment is divided into several drainage basins, $f=1,..,c$, which are located in the riparian countries $g=1,..,n$. Sources in each drainage basin emit pollutants E, where $E=N,P,CO$ (nitrogen, phosphorus, and CO_2e). Pollutants originate from different emission sources $o=1,...,m$, such as agriculture, and transports. However, the amount of nutrient load that enters the Baltic Sea from a given emission depends on the location of the source: upstream, U^{ofEg}, or downstream, D^{ofEg}. The difference in loads occurs because of the retention of nutrients during transport from an upstream source to the sea. The proportion of nutrients from upstream emissions source that reaches the sea, $\beta^{fEg} \in (0.1)$, is determined by hydrogeochemical and climate conditions and differs between drainage basins. Nutrient load from a downstream emissions source is not subject to retention. The total load of pollutants without abatement, or the business as usual (BAU) loads, from a drainage basin into the Baltic Sea or into the atmosphere, I^{ofEg}, is then the sum of emissions from all up- and downstream sources. This is written as

$$I^{ofEg} = \sum_o (D^{ofEg} + \beta^{fEg} U^{ofEg}). \quad (1)$$

In the case of CO_2e there is no up and down stream classification since all emissions are mixed in the atmosphere, and thus constitute direct emission in our setting.

In principle, there are three types of abatement measures in each drainage basin; abatement at upstream and downstream emission sources, A^{ofgU} and A^{ofgD} respectively, which include reductions in the use of inputs and creation of pollutant sink at the source, such as grassland on arable land. With respect to area of wetland creation, L^{fg}, this device acts as a filter for upstream nutrient load, but may also act as a source or sink of CO_2e emissions. All measures can affect at least one of the pollutants. The impact on pollutant reduction of an abatement measure at a source is assigned a linear form so that the change in each pollutant is proportional to the abatement for each country, b^{oEg}. Reductions in pollutant from abatement at up- and downstream emission sources are then written as $b^{oEg}A^{ofgU}$ and $b^{oEg}A^{ofgD}$, respectively.

The amount of pollutant sequestration by a wetland, Q^{fEg}, of area L^{fg} depends, for nitrogen and phosphorus, on the inflow of nutrient per unit area, W^{fEg}. The inflow is, in turn, a result of emission and abatement at upstream sources and the distance between the source and the wetland. It is here assumed that the potential wetlands are located downstream so the retention of nutrient during transport to the wetland is the same as to the coastal zone. This implies that the share of emissions reaching the wetland is $\beta^{fEg} \in (0.1)$ for all upstream emission sources in a drainage basin f in country g. The nutrient load to a unit area of wetlands site is then written as:

$$W^{fEg} = \beta^{fEg} \sum_o (U^{ofEg} - b^{oEg} A^{ofgU}). \quad (3)$$

Nutrient sequestration by wetlands is assigned a linear form in nutrient load and area, Q^{fEg} = $q^{fEg}W^{fEg}L^{fg}$ where $q^{fEg} \in (0.1)$ is the share of incoming load of a nutrient that is cleaned per unit wetland area. For CO_2e sequestration, the function is even more simple where $W^{fCOg} = \phi^{COg} L^{fg}$ and the sequestration, which can be negative, is simply a constant times the area of wetland. These simple formulations are explained by availability of data in the literature, which calculates the cleaning per unit wetland as shares of nutrient load entering a potential site (e.g., Byström et al., 2000) and the carbon sequestration as a constant per unit of land area (e.g. Janssen et al., 2005).

The nutrient discharges into the Baltic Sea and the CO_2e emissions from a country, M^{Eg}, are then determined by the exogenously given BAU nutrient load minus abatement by the three types of measures, which is written as:

$$M^{Eg} = \sum_f \left(I^{fEg} - \sum_o \left(b^{oEg}(A^{ofgD} + \beta^{fEg} A^{ofgU}) + q^{fEg}\beta^{fEg}(U^{ofgD} - b^{oEg}A^{ofgU})L^{fg}\right)\right) for\ E = N, P,$$

$$M^{Eg} = \sum_f \left(I^{fEg} - \sum_o \left(b^{oEg}(A^{ofgD} + \beta^{fEg} A^{ofgU}) + \varphi^{COg} L^{fg}\right)\right) \quad for\ E = CO. \tag{4}$$

The first term within parentheses at the right-hand side of eq. (4) shows the BAU loads from all sources in a drainage basin. The second term is the sum of abatement at emission sources and by wetlands.

Each abatement measure is subject to capacity constraints, written as:

$$A_t^{iofgU} \le \overline{A}^{iofgU},\ A_t^{iofgD} \le \overline{A}^{iofgD}, \text{ and } L_t^{ifg} \le \overline{L}^{ifg}. \tag{5}$$

Examples of constraints are the maximum area of land suitable for wetland construction and the upper limits of fossil fuel reductions. They are imposed to avoid drastic structural changes in the sectors, the analysis of which would require a general equilibrium framework.

Following practice applied in the eutrophication management and climate change policies targets are imposed on total loads of each of the three pollutants, which is written in equation 6 as:

$$\sum_g M^{gE} \le \overline{M}^{gE} \text{ for } E = N, P, CO. \tag{6}$$

The implementation of each abatement measure is associated with costs, which differ between measures and countries: $C^{og}(A^{ofgD})$, $C^{og}(A^{ofgU})$, and $C^g(L^{fg})$. The costs are assumed to be increasing and convex in their arguments.

The decision problem is formulated as the choice of measures and their locations, A^{ofgD}, A^{ofgU}, and L^{fg}, which minimize total cost for reaching targets on pollutant loads, according to

$$Min \sum_g \sum_f \sum_o C^{og}(A^{ofgD}) + C^{og}(A^{ofgU}) + C^g(L^{fg}) \tag{7}$$

s.t. (1)-(6)

The necessary conditions for minimizing costs under simultaneous management of all three emission targets are written as:

$$\frac{\partial C^{og}}{\partial A^{ofgU}} = -(\gamma^{ofgU} + \sum_E \lambda^E \psi^{fEg})$$

$$for\ E = N, P;\ f = 1,..,c;\ g = 1,..,k;\ o = 1,..l, \tag{8}$$

$$\frac{\partial C^{og}}{\partial A^{ofgD}} = -(\gamma^{ofgD} + \sum_E \lambda^E b^{oEg})$$

$$for\ E = N, P, CO;\ f = 1,..,c;\ g = 1,..,k;\ o = 1,..,l, \tag{9}$$

$$\frac{\partial C^g}{\partial L^{fg}} = -(\gamma^{fg} + \sum_E \lambda^E \kappa^{fEg}),$$

$$for\ E = N, P;\ f = 1,.,c;\ g = 1,.,k;\ i = 1,.,n \tag{10}$$

where $\psi^{fEg} = \beta^{fEg}(b^{oEg} - q^{fEg}L^{fg})$ and $\kappa^{fEg} = q^{fEg}\beta^{fEg}\sum_o(U^{ofgE} - b^{oEg}A^{ofgU})$ for $E = N, P$ and $\kappa^{fEg} = \varphi^{Eg}$ for $E=CO$, and $\gamma^{ofUg} \le 0$, $\gamma^{ofDg} \le 0$, $\gamma^{fg} \le 0$ and $\lambda^E \le 0$ are the Lagrange multipliers for the restriction on abatement capacities and on the emission targets. The left-hand sides of eqs. (8)-(10) are the marginal abatement cost at the source and the right hand sides show the impacts on the emission targets weighted by the Lagrange multipliers λ^E. When the capacity constraints are binding, γ^{ofUg}, γ^{ofDg}, and/or γ^{fg} are negative and reflect total cost savings in reaching the target of an additional unit of abatement capacity of the measure in question. The terms ψ^{fEg} and κ^{fEg} for $E = N, P$ show the mutual interdependence between upstream nutrient abatement and wetland sequestration, which is negative. The larger nutrient abatement at an upstream emission source the less nutrient load to the wetland and the smaller is the nutrient sequestration. Similarly, the higher the sequestration at the wetland, the smaller is the effect of a given upstream abatement on the Baltic Sea since part of the abatement would have been sequestered by the wetland.

The Lagrange multiplies $\lambda^E \le 0$ have an interesting interpretation since they measure the marginal abatement cost at the emission targets. They also show that the conditions for cost-effective solutions imply that marginal costs for reaching a pollutant emission targets shall be equal for all abatement measures and locations. In order to see this we solve for a λ^E in each of equations (8)-(10), and assume interior solutions, which gives:

$$\lambda^E = \frac{C^{og}_{A^{ofgU}} + \sum_{E \neq H} \lambda^H \psi^{fHg}}{\psi^{fEg}} = \frac{C^{og}_{A^{ofgD}} + \sum_{E \neq H} \lambda^H b^{fHg}}{b^{fEg}} =$$

$$\frac{C^{g}_{L^{fg}} + \sum_{E \neq H} \lambda^H \kappa^{fHg}}{\kappa^{fEg}}. \tag{11}$$

In order to interpret the condition expressed in eq. (11) we consider the target for nitrogen reduction, i.e. $E=N$. The condition then states that in a cost-effective solution the marginal costs of nitrogen reduction to the Baltic Sea are equal for all measures. This includes the marginal nitrogen abatement cost at the source, the first term in the numerators in (11), the impact on the nitrogen load to the Baltic Sea shown by the denominators, and the weighted effects on the phosphorus and CO_2 emission target shown by the second term in the numerators. The larger the impact on the Baltic Sea, i.e. the term in the denominator, the lower is the marginal cost of nutrient reduction to the sea of the measure in question. The marginal cost is also reduced by the weighted impacts on the phosphorus and CO_2 emission targets since $\lambda^E \leq 0$.

The only difference between the conditions for multi-target management as shown in (11) and the single-target management is the summation over E in the numerators, since only one pollutant is considered under separate management. Recall that $\lambda^E \leq 0$, which means that the marginal cost and total cost of reaching the target for a pollutant E is always lower under multi-target management than single-target management when there exists at least one abatement measure that affects more than one pollutant. The magnitude of this cost difference is determined by empirical calculations.

2. Data retrieval

The Baltic Sea catchment covers an area of approximately 1800 km^2 and a population of 80 million (Gren et al., 2000). The entire catchment includes 14 different countries (Norway, Sweden, Finland, Russian Federation, Belarus, Ukraine, Estonia, Latvia, Lithuania, Poland, Czech Republic, Slovakia, Germany, and Denmark). Nine of them have coastal zones in the Baltic Sea; Germany, Sweden, Finland, Poland, Estonia, Latvia, Lithuania, and Russian federation, which cover approximately 90% of the entire catchment (Gren et al., 2000). In this study we therefore include only these riparian countries when calculating costs for nutrient and climate change management.

The nine riparian countries differ with respect to land cover, population and economic prosperity as measured by GDP/capita and total (Table 1).

Table 1. Land uses, population, and GDP in the countries in the Baltic Sea catchment

Country	Share of total land cover in 1995[1]		Share of total population in 2011[2]	GDP/capita in 2011[3], thousand Euro	Share of total GDP
	Total area	Agriculture land			
Germany	0.021	0.054	0.043	34	0.078
Sweden	0.259	0.073	0.122	44	0.254
Denmark	0.020	0.057	0.060	45	0.142
Finland	0.181	0.050	0.071	37	0.127
Poland	0.189	0.432	0.494	10	0.267
Estonia	0.028	0.047	0.021	14	0.016
Latvia	0.040	0.047	0.029	11	0.018
Lithuania	0.039	0.085	0.044	12	0.028
Russia	0.224	0.155	0.115	11	0.070
Total shares	1	1	1		1
Total number	1651 thousand km^2	463 thousand km^2	76905 thousand	20 thousand Euro in average	1517 billion Euro

Notes: [1]Gren et al. (2000); [2]Gren et al. (2000) allocation in drainage basins with update in Nationmaster (2014); [3] IMF (2014).

The figures presented in Table 1 give some indications on the uneven distribution of land, human resources and prosperity among the countries. Four countries, Sweden, Finland, Poland and Russian Federation cover 85% of the total land area. Approximately 75% of the total population lives in three of these countries (Sweden, Poland, and Russia), and half of the total GDP in 2011 emerges from Sweden and Poland. However, the GDP/capita is three times higher in Sweden than in Poland making the economic conditions for nutrient and climate change mitigation quite unequal in these and other riparian countries.

With respect to environmental policy the nine riparian countries have signed three international governmental agreements on nutrient load reductions to the Baltic Sea in order to combat eutrophication (Helcom, 1988; 2007; 2013). The Baltic Sea is not only the largest brackish water sea in the world, but also the sea with the largest areas of dead sea bottoms caused by eutrophication (Conley et al., 2009). This is not a new finding; signs of damages from eutrophication, such as higher frequency of toxic algal blooms, declining populations of commercial fish, and lower water transparency, were detected already in the 1960s. Therefore, an international administrative body Helcom was established in 1974 in order to monitor status of the sea and coordinate mitigation actions.

Except for Russia, all the Baltic Sea countries participate in the EU 2020 climate policy, the purposes of which is to the reduce emission by 20% from the 1990 level, to increase energy efficiency and the use of renewable energy. The reduction in emissions is obtained by two pillars; the EU ETS and the national commitment plans. However, this study includes only 8 of 27 countries in the EU, and a thorough modelling of impacts on the EU climate policy from nutrient abatement policies for the Baltic Sea would require modelling of both these regions, which is beyond the purpose of this paper.

2.1. Nutrient and CO_2e emission. The study makes use of data on nutrient emissions from Gren et al. (2008) and on GHG emissions from Gren et al. (2012). The Gren et al. (2008) study calculates nutrient loads into the Baltic Sea based on data on nutrient emissions from different sources; atmospheric deposition from combustion of petroleum products and ammonia releases from livestock, leaching of fertilisers, manure, and from arable soils, and discharges of sewage from industry and households. Since the transports of nutrients from a given deposition on land differ among drainage basins, the entire Baltic Sea catchment is divided into 23 sub drainage basins. Nutrient load into the Baltic are then calculated using data on nutrient leaching and retention for each sub drainage basin which corresponds to b^{iE} in Section 2. Atmospheric emissions are treated as direct discharges into the sea with data on the share of total emission which is deposited on the Baltic Sea.

Location of the source does not matter for the climate impact and the data on CO_2e emission are obtained directly from the emission sources, which are reported in Gren et al. (2012). Multi-pollutant emissions from a source is of particular interest in this study, and we then present calculated nitrogen loads from combustion of fossil fuels and CO_2e emission from the agricultural sectors (Table 2).

Table 2. Emissions of CO_2e, and nutrient loads into the Baltic Sea

Country	CO_2e, million ton			Nitrogen, N, thousand ton			Phosphorus, P, thousand ton[5]
	Fossil fuel[1]	Agric.[2]	Total	Fossil fuel[3]	Agric. sewage[4]	Total	
Germany	69.3	7.4	76.7	3.5	34.8	38.3	0.4
Sweden	41.2	7.3	48.5	6	71.7	77.7	1.6
Denmark	39.5	15	54.5	5.6	45.2	50.8	1.0
Finland	53.4	4.3	57.7	5.7	47.3	53	1.6
Poland	299.9	24.8	324.7	14.4	222.2	236.6	15.2
Estonia	27.1	2.4	29.5	3.3	54.4	57.7	1.6
Latvia	7.2	2.2	9.4	1	46.2	47.2	2.9
Lithuania	18.2	3.3	21.5	1.2	82.5	83.7	2.8
Russia	41.5	10.9	52.4	6.4	60.1	66.5	3.3
Total	597.3	77.6	674.9	47.1	664.4	711.5	30.4

Notes: [1]Gren et al. (2012); [2,3]Table A1 in appendix; [4,5]Gren et al. (2008).

The emissions of CO_2e in the Baltic Sea regions correspond to approximately 16% of the total emissions in EU (Gren et al., 2012). The contribution from agriculture amounts to approximately 11% of total emission from the region. The share of the contribution from the fossil fuel sectors to nitrogen load into the Baltic Sea is smaller and amounts to 6% of the total load of 711.5 kton N. With respect to allocation of emissions among countries Poland is the major emission source of all three pollutants, which is explained by its relatively large shares of total population and land areas as shown in Table 1, but also on the reliance on coal for energy production (Gren et al., 2012). It might be more realistic to consider only the non-trading sectors using fossil fuels in a Baltic Sea management scheme, since the trading sectors have the possibility to exchange permits at the EU ETS. When only the non-trading sectors are considered, the total CO_2e emissions presented in Table 2 are reduced by 56%, the level of which differs between the countries (Table 3).

Table 3. CO_2e emissions and N emission from the non-trading sectors

Country	CO_2e, million ton			Nitrogen, N, thousand ton	
	Fossil fuel	Total incl.		Fossil fuel	Total including agricultural and sewage
		Non-trad[1] sectors	Share of all agricultural sectors		
Germany	29.8	0.43	37.2	1.4	36.2
Sweden	26.3	0.64	33.6	2.9	74.6
Denmark	20.2	0.51	35.2	1.8	47

Table 3 (cont.). CO_2e emissions and N emission from the non-trading sectors

Country	CO_2e, million ton			Nitrogen, N, thousand ton	
	Fossil fuel	Total incl.		Fossil fuel	Total including agricultural and sewage
Finland	19.0	0.36	23.3	2.2	49.5
Poland	109.3	0.36	134.1	7.1	229.3
Estonia	13.4	0.49	15.8	2.1	56.5
Latvia	2.29	0.65	4.49	0.4	46.6
Lithuania	6.09	0.53	9.39	0.8	83.3
Russia	41.5	1.00	52.4	6.4	71.6
Total	267.88	0.44	345.48	25.1	694.6

The agriculture sector's contribution corresponds to approximately 22% of total CO_2e emissions when only non-trading sectors are considered. The associated effect of the impact of combustion of fossil fuel on N loads to the Baltic Sea is small, an overall reduction by 2%.

2.3. Abatement measures and costs. The relatively small shares of agriculture's contribution to CO_2e and that of the fossil fuel sectors' to nitrogen load may lead to small cost savings from multi-target management compared with single target. However, most abatement measures included in this study are multifunctional, which reduces costs for multi-target management. More precisely, the abatement measures included in this study mainly focused on fossil fuel are: decreased use of fossil fuels, and replacement of fossil fuel for heating by wind, solar power, and bioenergy. Included abatement measures directed towards nutrient loads are; increased nutrient cleaning capacity at sewage treatment plants, catalysts in cars and ships, flue gas cleaning in stationary combustion sources, and reductions in the agricultural deposition of fertilisers and manure, cultivation of so called catch crops, energy forests, ley grass, and creation of wetlands. Catch crops refer to certain grass crops, which are drilled at the same time as the ordinary spring crop but the growth, and thereby the use of remaining nutrients in the soil, is concentrated to the period subsequent to the ordinary crop harvest. Almost all of these measures are expected to have impacts on all three pollutants (Table 4).

Table 4. Abatement measures included in the study and classification of their effects

Measure	Effect on		
	CO_2e	Nitrogen	Phosphorus
Increased cleaning of nutrients at sewage treatment plants		X	X
Reductions in the use of fossil fuel	X	X	
Reductions in fertilizer use	X	X	X
Reduction in livestock holding	X	X	X
Creation of wetlands on arable land	X	X	X
Catch crops	X	X	X
Grassland on arable land	X	X	X
Energy forest on arable land	X	X	X
Wind power	X	X	
Solar power	X	X	

Data on impacts on nutrient loads by wetlands, catch crops, grassland and bioenergy are obtained from Gren et al. (2008). Corresponding data for CO_2e are obtained from the countries' report to UNFCCC (2014), and the impacts are then calculated by taking the difference in carbon soil source/sink between arable land and the land conversion in question (Table A2 in appendix). The renewable energy sources wind power, solar cells, and bioenergy also give rise to replacement of fossil fuels. They are assumed to replace oil for hea-ting where 1 MWh generates 690 ton CO_2 (e.g. EPA, 2014).

Costs of reductions in the use of fossil fuel, fertilisers, and livestock reductions are calculated as decreases in consumer surplus, i.e. the reduction in profits from decreases in the use of the inputs. Following Gren et al. (2008; 2012) and linear demand functions are assumed which are obtained from data on demand elasticities and evaluated at the quantities and price levels in 2011 for fossil fuels and 2008 level for fertilisers. Costs of livestock reductions are assumed to be constant per unit of animal. Except for catch crops, costs for converting arable land to either of the land uses listed in Table 4 are calculated as opportunity cost of land. This is, in turn, calculated as decreases in producer surplus, which are calculated by assigning a linear supply function of arable land evaluated at the supply elasticity of 0.2 (Gren et al., 2012) and actual prices and quantities of arable land as reported in Gren et al. (2008). Cost functions for wind power and solar cells are given a quadratic form where the coefficients are obtained from Gren et al. (2014). Finally, abatement cost functions for increased nutrient cleaning at sewage treatment and cultivation of catch crops are given a linear form the quantification of which are found in Gren et al. (2008).

In addition, capacity constraints are imposed on all measures due to the static version of our model. In a relatively short period of time, approximately 5 years, it is not possible to account for drastic structural changes in our modelling framework. Restrictions are therefore imposed on all inputs corresponding to a maximum level of 60% of the business as usual (BAU) levels. The corresponding BAU emission levels are reported in Tables 2 and 3.

2.3. Pollutant emission targets. The targets are based on the intergovernmental agreements for nutrient load reductions by Helcom (2013) and the EU 2020 climate policy. Helcom (2013) envisages that phosphorus loads need to be reduced by 60% and nitrogen loads by 23% in order to restore the sea. According to the EU 2020 policy, total carbon dioxide emission is to be reduced by 20% in 2020 compared with the level in 1990. Since 1990, the EU member countries in the Baltic Sea drainage basin has reduced total emissions by approximately 10%, and additional 10% reduction is then needed to fulfil the commitment under the EU policy (Gren et al., 2012). In this study, we therefore impose a reduction by 10%.

We thus calculate costs for single- and multi-target management where the nitrogen and phosphorus are reduced by the recommendations set by Helcom (2013), i.e. by 23% and 60% respectively, and the CO_2e emissions are decreased reduced by 10% from the business as usual (BAU) levels presented in Table 2 Calculations are made for all sectors emitting CO_2e and when only the non-trading sectors participate. The reduction levels constitute the reference case, and we calculate costs also for other reduction levels of the pollutants in order to see how the stringency in the targets affects the gains from multi-target management.

3. Cost effective pollutant management

When all sectors are included, the total abatement cost can be reduced by approximately 15% from a move from single to multi-target management (Table 5).

Table 5. Abatement cost in billion Euro under separate and simultaneous reductions in N, P, and CO_2e by 23%, 60%, and 10%, respectively, from the BAU level

	Separate reductions				Simultaneous reductions		
	N	P	CO_2e	Total cost	Total cost	Gain[1]	Gain in %
Germany	71	6	203	280	240	40	14.3
Sweden	57	121	268	446	411	35	7.9
Denmark	7	128	179	314	300	14	4.5
Finland	78	253	213	544	338	206	37.9
Poland	516	2422	1198	4136	3323	813	19.7
Estonia	77	113	133	323	242	81	25.1
Latvia	39	190	84	313	270	43	13.7
Lithuania	91	332	146	569	473	96	16.9
Russia	196	409	140	745	781	-36	-4.8
Total	1132	3974	2564	7670	6378	1292	16.9
Marginal costs, MC	17.3/kg N	496/kg P	43.7/ton CO_2e		MC^N =8.4/kg N; MC^P = 480/kg P; MC^{CO2e} = 39.8/ton CO_2e		
'Free' reduction in % of BAU level	P: 6.5 CO_{2E}:0.3	N: 17.3 CO_{2E}: 0.2	N: 11.5 P: 4.8		N: 12.7 P: 2CO_2e: 0.5		

Notes: [1]Difference in total abatement cost between separate and simultaneous pollutant reductions. [2]Calcuted as the difference in target reductions and levels at the optimal MC under simultaneous reductions.

The total cost under single target management for CO_2e emission reduction corresponds to 0.17% of total GDP. This can be compared with estimates of costs for a cost-effective 20% reduction for all EU countries which ranges between 0.3 and 0.5% of total EU GDP (see Börhinger et al., 2009 for a review). However, the marginal abatement cost of 43.7 Euro/ton CO_2e is of the same level as for achieving 20% reduction under the E2020 climate policy, which ranges from 25 to 57 Euro/ton (Stankeviciute et al., 2007). The steeper increase in costs in our model can be explained by the method as such which does not account for dispersal effects of reductions in the sectors reducing their CO_2e emissions. Another explanation is the inclusion of more and probably low cost options in terms of land use changes in our study which makes MC of initial reductions relatively low. A third possible reason is the difference in structure of the Baltic Sea countries compared with the other EU countries with respect to energy and land use composition.

The cost of nitrogen and phosphorus reduction, which total to 4794 billion Euro under separate management can be compared with estimates obtained by the studies calculating only costs of the BSAP agreement (Elofsson, 2010; Gren and Destouni, 2012). The cost obtained by Gren and Destouni (2012) amounts to approximately 2.5 billion Euro and that by Elofsson (2010) to 3.9 billion Euro. The lower estimates in these studies are mainly attributable to the earlier time period for which costs are estimated, 2007 compared with 2011 in our study, which implies lower cost because of inflation rate during the period and to less room for low cost measures since they have already been implemented. Further, both studies calculate costs for simultaneous nitrogen and phosphorus reductions. Unfortunately, none of the two studies delivered information on marginal abatement costs.

In total, the gain from moving from single target strategy to simultaneous reduction amounts to 1072 billion Euro or approximately 15% of the total cost under separate management. This corresponds to approximately 0.07% of total GDP. However, the gain is unevenly distributed among the countries depending on the abatement costs for the different measures and their multi-functionality with respect to effects on several pollutants. Poland faces the largest part of the gain, which amounts to 585 billion Euro, mainly because of the decreases in reductions from measures affecting more than one pollutant. On the other hand, the cost increases by 2.6% under simultaneous abatement for Russia because of the availability of relatively much and low cost abatement by multifunctional measures.

The cost decrease under simultaneous abatement is obtained mainly because of the ‘free of charge’ reduction of nitrogen under the simultaneous reduction strategy. We can note that the single pollutant strategy results in reductions in other pollutants than the targeted as shown by the last row in Table 5. For example, the reduction of 23% in nitrogen generates decreases in phosphorus loads by 6.5% and in CO_2e by 0.3%. The simultaneous reduction of both pollutants is obtained by use of land use measures and for CO_2e by fertilizer and livestock reduction. Similarly, the targeted CO_2e reduction results in N reduction of 11% and P decrease by 4.8%, both of which are obtained by energy crops and (for N) by reductions in airborne emissions. The neglect of these impacts thus results in larger reductions than necessary, which entails higher cost. In the cost-effective simultaneous management these ‘free’ reductions are accounted for, which results in lower reduction requirement as shown by the last column in the last row in Table 5. Both phosphorus and CO_2e reductions contribute to simultaneous nitrogen reductions, which amount to 12.7% in the cost-effective solution. This means that the nitrogen load needs to be decreased by only 11.3% in order to achieve the target reduction of 23%. This can also be seen from the large decrease in the marginal abatement cost of nitrogen, which is reduced from 17.3 Euro to 8.3 Euro/kg N reduction. The effects on the other pollutants are more modest, only 2% lower for phosphorus and 0.3% for CO_2e.

The pattern of results is similar when we include only the sectors not trading in the EU-ETS. The 10% target in CO_2e reductions is then measured from the BAU level of the non-trading sectors, which implies a reduction by 38 instead of 71 million tons as can be seen from Tables 2 and 3. There are two main difference compared with when all sectors are included; the total abatement cost decreases because of lower reduction need in CO_2e, and no country makes a loss from simultaneous management (Table A3).

In order to investigate the effects on gains from simultaneous management from changes in reduction levels of the pollutants we calculate costs under separate and simultaneous management for the same percentage reduction in each pollutant at different levels (Figure 1).

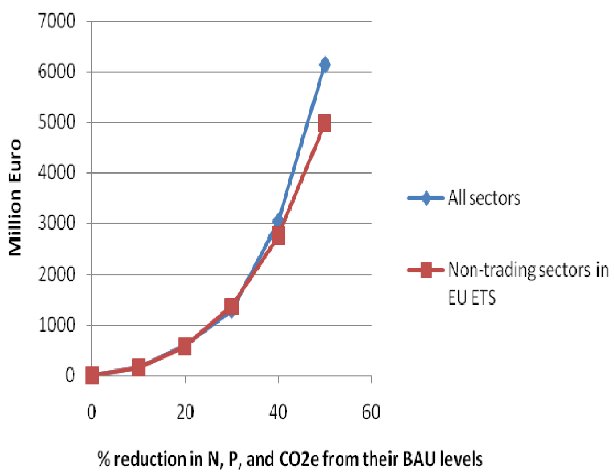

Fig. 1. Gains from simultaneous pollutant management for different levels of uniform pollutant reductions for all sectors and when only non-trading sectors in EU ETS are included

The gains increase for tighter environmental stringency in targets, and can amount to approximately 6150 million Euro when all three pollutants are reduced by 50% and all sectors are included. This corresponds to approximately 0.4% of total GDP.

The gains are in the same order of magnitude when only non-trading sectors are included up to 40% reduction, but then differ compared with when all sectors are included. However, they are larger in relatively terms since the total costs are lower because of lower CO_2e emissions and, hence, reduction requirements. At the 50% reduction level the decrease in costs when only non-trading sectors are included is 7% and 4.9% when all sectors are considered.

Conclusions

A number of emission sources and abatement measures affect several pollutants at the same time, either as complements or substitutes. In the case of eutrophication and climate change, fossil fuel combustion generates CO_2 and NO_x emission with implications for climate change and eutrophication. Similarly, CO_2e and NH_4 are emitted from livestock holding and fertiliser use. But not only sources show multi pollutant impact but also abatement measures, which can be implemented at the sources but also at other locations, such as wetland creation and mussel farming which increase pollutant sequestration. It might then seem self-evident that simultaneous management of several pollutant targets would result in lower total abatement cost then separate treatment. However, the magnitude of this cost difference and allocation of gains from simultaneous management are less obvious.

Our study showed that total cost can be reduced by at least 15% when two environmental targets are managed at the same time; maximum nutrient loads to the Baltic Sea determined by Helcom (2013) and maximum CO2e emission as set by the EU 2020 policy. The cost saving amounts to 1250 million Euro, which, in turn corresponds to 0.4% of total GDP of the nine riparian regions. The main reason for this cost saving is the complementarity in reductions of both phosphorus and CO2e with nitrogen decreases. Countries will thus make gains from lower overall reduction needs, but may also face increased costs if equipped with relatively large capacity of low cost multifunctional abatement measures. In our study, Poland makes the largest cost savings but drainage basins in the Russian Federation may in fact face higher costs since more abatement with multifunctional measures is carried out in these regions. It should be noted that our study is limited to CO2e and nutrient emissions within the Baltic Sea region. It does not consider the global and transboundary effects of CO2e and air borne nitrogen emission outside this region. Further, reductions in air born nitrogen emissions in the Baltic Sea regions which affect other countries are not included.

However, the actual implementation of a multi-target strategy requires allowance for pollutant reduction in several policy systems. For example, creation of wetlands must be deducted from loads of nitrogen, phosphorus, and CO_2e. This can be obtained by an offset system where actors obtain credits for pollutant sequestration which can be deducted from their pollutant emissions. Another possibility is to include the abatement measures in the policy system where, for example, wetland pollutant sequestration can be traded on the EU ETS, and national tax systems. The latter would then imply a negative tax, where a firm producing pollutant sequestration obtains subsidies for sequestration of all three pollutants. This might be feasible at a reasonable transaction cost for abatement of CO_2e and N emissions from combustion of fossil fuel, livestock holdings, and fertilizers, for which there exist conversion factors. However, it can be more difficult to implement for land use measures because of the difficulties to monitor and verify sequestration, and to secure additionality and permanence in the sequestration (see Aklilu and Gren, 2014 for a review). The potential cost savings from moving to multi-target management are then smaller than pointed out in this study. There is an emerging body of literature on the design of policies for multi-target achievement (e.g. Ambec and Coria, 2013). Our results show that the potential of such design with respect to cost savings for reaching emission targets can be substantial.

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Appendix

Table A1. CO_2e emissions from fertilisers[1], livestock and land uses

	Livestock kg CO_2e/animal unit[2]			Land kg CO_2e / ha [3]			
	Cattle (beef)	Pig	Chicken	Arable	Grassland	Wetland	Energy forest
Germany	2198	868	6.3	0.12			
Sweden	2895	736	0	69	-123	2	-490
Denmark	2731	670	4.1	121	111	44	-2817
Finland	2565	831	5.5	85	-56	73	-568
Poland	2280	453	4.4	20	4	12	-932
Estonia	2363	482	0	112	-59	61	-714
Latvia	2480	486	5.4	34	0	12	-1413
Lithuania	2228	424	4.7	48	-64	44	-1454
Russia[3]	2480	486	5.4	34	0	12	-1413

Notes: [1]Fertilizers emission of CO_2e are assumed to be the same for all countries and amount to 6.8 kg CO_2e /kg N nitrogen emission (Sonesson et al., 2009); [2]Leip et al. (2010); [3]NFCCC (2014); [4]Assumed to be the same as in Latvia.

Table A2. Carbon sequestration, ton C/ha

	Forest	Arable land	Grass land	Wetland
Germany	0.839	-0.031	0.108	-0.815
Sweden	0.49	-0.069	0.163	-0.012
Denmark	2.817	-0.121	-0.111	-0.041
Finland	0.568	-0.085	0.056	-0.073
Poland	0.93	-0.020	-0.004	-0.012
Estonia	0.714	-0.112	0.059	-0.061
Latvia	1.413	-0.034	0	-0.012
Lithuania	1.454	-0.048	0.064	-0.044
Russia[1]	0.714	-0.121	0.059	-0.061

Source: UNFCCC (2014).
Notes: [1]Assumed to be the same as in Estonia since only a fraction of Russian Federation is located in the drainage basin.

Table A3. Abatement cost in million Euro under separate and simultaneous reductions in N, P, and CO2e from the sectors not trading in the EU-ETS by 23%, 60%, and 10%, respectively, from the BAU level

	Separate reductions				Simultaneous reduction		
	N	P	CO_2e	Total cost	Total cost	Gain1	Gain in %
Germany	71	6	82	159	129	30	18.9
Sweden	57	121	169	347	311	36	10.4
Denmark	7	128	101	236	224	12	5.1
Finland	78	253	96	427	230	197	46.1
Poland	515	2421	719	3655	2886	769	21.0
Estonia	76	113	75	264	189	75	28.4
Latvia	7	190	69	266	256	10	3.8
Lithuania	86	333	124	543	451	92	16.9
Russia	196	409	120	725	708	17	2.3
Total	1093	3974	1555	6622	5384	1238	18.7
Marginal costs, MC	17.3	496	43.6		MCN = 8.4; MCP = 480; MCCO2e = 33.8		
% reduction in 'the other' pollutants	P: 7.9 CO2E :0.6	N: 13.2 CO2E: 0.3	N: 8.0 P: 4.8		'Free' reduction in % from BAU2: N; 11.5 P; 2 CO2e: 4.5		

Notes: [1]Difference in total abatement cost between separate and simultaneous pollutant reductions. [2]Calcuted as the difference in target reductions and levels at the optimal MC under simultaneous reductions.