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Abstract/ Summary

The Baltic Sea suffers from eutrophication, which is due to leaking soil and emissions from industries, sewage plants and the agricultural sector. Helcom, the Convention of Helsinki has stated that the abatement targets for phosphorus and nitrogen have still not been reached. Research has shown that mussel farming could function as an abatement technique at a low cost. The purpose of this paper is to estimate if mussel farming could function as an offset in mitigating eutrophication in the Baltic Sea. Additional, the purpose is also to estimate an uncertainty discount for mussel farming since the mussel has an uncertainty treatment capacity. The theoretical framework is a mathematical optimization model where the cost of the total abatement in the sea is minimized subject to the level of total abatement, which includes other abatement techniques plus the abatement level of mussel farming, should be equal or larger than the abatement requirement that is set for the country. The cost minimization problem is then solved by the Lagrange method. The result shows that Sweden and Germany would benefit when crediting mussels for nitrogen. For phosphorus, Sweden, Poland, Denmark, Germany and Lithuania would benefit from introducing mussel farming. When including the uncertainty factor the level of mussel farming decreases in all countries. In a scenario analysis the marginal cost of mussel farming were given weights of 0.5 for nitrogen and phosphorus respectively. The result showed that additional countries would benefit from introducing mussel farming as an offset.

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1. Introduction

The Baltic Sea is said to be one of the most polluted seas in the world and the most worrisome pollutants are phosphorus and nitrogen (Arc2020, 2014). Helcom, the convention of Helsinki, which aim is to protect the marine environment in the Baltic Sea, states in their action plan that the Baltic Sea is highly affected by the eutrophication, which is the ecosystem's response on an increase in phosphorus and nitrogen loads. It is stated that almost 75 percentages of the nitrogen load and 95 percentages of the phosphorus that enters the sea are transported by rivers and other water sources (Helcom, 2016a). The nutrients, in turn, reach the water sources through leaching in soil and discharges from industries such as energy production and transports, but also from the agricultural sector, due to fertilizing farmland (Helcom, 2016b).

Alger bloom and bloom of cyanobacteria contribute to the eutrophication in the Baltic Sea. Cyanobacteria fixates nitrogen and therefor add additional nitrogen to the environmental system. An abnormal increase in cyanobacteria results in an surplus of organic material that is decomposed in the sea bed. This results in an anoxic environment which results in a reduction of other organisms. For cyanobacteria to grow a large share of phosphorus is needed and a downhill spiral for the marine environment in the Baltic Sea is a fact. The phosphorus load is related to the load of nitrogen which means that , both nitrogen and phosphorus will have to be abated in order to solve the problem with eutrophication (Havet, u.d.a).

The present abatement of phosphorus and nitrogen in the Baltic Sea is mainly derived from the agricultural sector since it is the main contributor to the eutrophication. Other abatement techniques that are used in the countries near the Baltic Sea are improved cleaning at sewage plants for industry and for households. Some models include on reduction of airborne emissions, according to Gren et.al (2008).

Gren, Lindahl, Lindqvist (2009) state that many different abatement techniques with low costs have been implemented in the Baltic Sea but the nutrient targets have still not been reached. This gives incentives to further research on additional abatement techniques, which will contribute to achieve the targets on reductions in nitrogen and phosphorus loads in the most economic efficient approach.

According to Gren, Lindahl and Lindqvist (2009) mussel farming could have the potential of being an abatement technique. Mussels have a comparative advantage since the mussel is a multifunctional organism, which can absorb both phosphorus, and nitrogen, compared to other common abatement techniques like sewage plants which usually only can abate one element at a time.

The blue mussel would be the most potential mussel species of interest for abatement in the Baltic Sea. The blue mussel is a filter feeder, which implies that the mussel nourished by filtrating water and detaches plankton. From plankton the mussel absorb nutrient as phosphorus and nitrogen (Rosenberg, Loo, 1983). The blue mussel in the Baltic Sea is cultured by long line, which implies that the mussel grows on a 200 meters line and 4-8 meters deep. Additional, the mussel's growth is dependent on nutrient content and salinity in the water, which strengthens the hypothesis that mussel could function as an abatement method. The Baltic Sea has a relatively high level of nutrient content and the salinity in the water in some areas is within the range that mussels require (Lindahl, u.d.).

Previous studies (e.g. Gren, Lindahl and Lindqvist, 2009; Hart et.al, 2005; Neumann, Schernewski and Stybel, 2012) show that mussel farming might have abatement potential in the Baltic Sea, which motivates this paper. There are no studies found of the potential of mussel farming used as an offset for the Baltic Sea countries. Offset is defined as the possibility for a sector in a compliance or voluntary market to buy abatement from other sectors. For example, sewage treatment plants are required to increase the degree of nutrient cleaning in several countries. Mussel farming as an offset would allow these plants to purchase abatement from a mussel farmer and include this as abatement.

A disputed attempt to implement mussel farms as an abatement technique has been done in Lysekil, a municipality in the west coast of Sweden. The sewage plants have exemption to avoid expanding the sewage plant in the municipality and instead invest in mussel farms in Skagerrak. The outcome of the investment differs depending on which operator that is asked but the main factors that the opponents have highlighted are that mussel farms require tranquil water near the coastline. This would mean that mussel farms would have to be implemented in shore protection areas, which could affect the outdoor life in the region (SVT, 2008). In 2013 a case in the Court of Appeal in Sweden (case number M 8456-12) however states that mussel farming in Lysekil did not contribute to a disrupted outdoor life or had any negative water environmental effects in the basin where the farm was implemented. It was also stated that mussel farms can but do not have to be implemented in shore-protected areas.

In order for mussel farming to be a potential abatement method, the cost of abating one more unit of phosphorus or nitrogen would have to be equal or lower than for other abatement systems. In other words, to be interesting as an abatement method, the marginal cost for mussel farming must be equal or lower than that for any other abatement technique. If not, there would be no incentives to use mussel farming as an offset for farmers or the industry sector in the Baltic Sea.

However, mussel farming has a cost disadvantage since mussels depend on weather and water conditions and is thus uncertain. It also makes nutrient abatement more uncertain than current abatement techniques.

1.1 Objectives of the study

The overall objective is to examine if mussel farming can be used as an offset in mitigating eutrophication in the Baltic Sea. The more specific research question is narrowed down into one question;

In a cost effective allocation of nutrient abatement, for which countries with coastline to the Baltic Sea could mussel farming be an abatement alternative for nitrogen and phosphorus?

By identifying the marginal cost function of mussel farming and the marginal cost function of other abatement techniques one is able to make a comparison and to find the most cost-effective allocation of abatement. More precise objectives of the research are stated below.

- Derive the marginal cost for phosphorus and nitrogen for mussel farming, with and without uncertainty
- Estimate uncertainty discount factor for mussel farming
- Derive the marginal cost for other abatement techniques
- Derive for which countries mussel farming could be implemented
- Derive the abatement allocation between mussel farming and other abatement techniques, with and without uncertainty
- Derive consequence of a policy change where double dipping is allowed, i.e. where mussel farming can achieve credits for abatement of both nitrogen and phosphorus

1.2 Limitations

The hypothesis of the research is that mussel farming would be interesting to use as an offset for several countries with coastline to the Baltic Sea. This implies that the agricultural- and the industry sector could invest in mussel farming instead of in more expensive abatement techniques in their own sector to reach their abatement targets. More specifically, t the hypothesis is that the potential level of mussel farming differs between countries and is depending on abatement requirement, water conditions in the part of the Baltic Sea the country is located in and the cost of other abatement techniques in the country of interest. An additional hypothesis is that some uncertainty in abatement for mussel farming is prevailing and that the uncertainty affects the allocation of abatement between mussel farming and other abatement techniques.

Due to inadequate data on cost functions of mussel farming the marginal cost function is assumed to be constant. This assumption affects the allocation of abatement significantly since a different shaped marginal cost function would result in a different abatement allocation.

The study will not include a potential profit from selling the mussels, which is another factor that would affect the allocation of abatement between mussel farming an other techniques. There is a market for mussels for human use which would reduce the cost of mussel farming, but the mussels growing in the Baltic Sea are too small to be used for human consumption. Furthermore, eventual regional economic effects in terms of e.g. employment are excluded.

It could however be questioned if there should be further research on abatement in the Baltic Sea instead of focusing on the initial problem; the pollution that causes the environmental disequilibrium in nutrient loads and hence the eutrophication in the Baltic Sea. It might be argued that research should focus on methods to decrease the pollution instead of methods that reduce pollution from emission sources. In this study it is nevertheless focused on the cost effective abatement, and it is not given any ethical weight to the polluters in question.

1.3 Outline

The outline if the paper is at first a review of literature of the topic, followed by a theoretical framework that explains how the cost advantages of mussel farming are derived. The theory section is followed by description of data and presentation of result. Additional simulation of the results, due to a potential policy change, follows. Lastly, a conclusion and a discussion of the result are given.

2. Literature review

The literature on the potential of using mussel farms as an offset in mitigating eutrophication in the Baltic Sea or other water basins is sparse. Some literature has examined the value and potential of mussel farming as an abatement technique. However, there is no study adding uncertainty aspects to the value of the mussel farms.

Gren, Lindahl and Lindqvist (2009) examined the value of mussel farming for combating eutrophication in the Baltic Sea. The authors calculate the value of mussel farming with a replacement cost method. This implies that the value of the mussel is the cost saved by replacing other abatement measures with higher costs.

The Baltic Sea was divided into different basins to be able to control for different climate and biological conditions in the cost minimization model. The potential revenues that were used in the paper are the value of mussels for human or animal food. The uncertainty in the calculations, according to the authors, is that the mussel's growth rate is depending on the salinity of the water, which differs a lot in the seven marine basins. There is also an uncertainty if the mussels could be sold for human consumption. The result shows that the constant marginal cost for mussel farming can lie between different levels, €0 per kg and €63.5 per kg for nitrogen and €900 per kg phosphorus respectively. The difference in marginal cost is due to different calculations when including with and without sales and high and low growth rate of the mussel (Gren, Lindahl, Lindqvist, 2009).

Gren et al. (2009) is close to the research in this study. However, the authors only state that the there is uncertainty of the abatement technology, but do not consider it in the calculations of the value of mussels. An uncertainty factor will however be examined in this study. Lindqvist (2008) states in his paper that mussel farming as an eutrophication reducer is sensitive to a lot of economic and biologic circumstances and that the value of mussel farming, without taking risk into account, could be biased. The author confirms the importance of risk discounting when solving optimization problem regarding mussel farming and other abatement techniques in the Baltic Sea due to the abatement uncertainty, which gives additional support to examine the uncertainty in mussel farming as an abatement technique.

Neumann, Schernewski and Stybel (2012) studied the potential of the zebra mussel as an eutrophication combatant in the Oder Lagoon, a lagoon that ends in the Baltic Sea. The economic model that has been used in the paper consists of several sub models in order to capture all values of mussel farming, costs and potential revenues. The potential cost of mussel farming were calculated to €0.2 per kg. The potential revenue is derived from 5 percentage sales for human consumption at a price of €0.3 per kg and 90 percentage sales in animal feed and fertilizer at a price between €0.023 per kg and €0.05 per kg. The authors state further that if mussel farming could be used as an abatement technique, the cost of mussel farming would decrease. If mussel farms would be used in the lagoon the mussel farmers would need to be financially compensated, according to the authors. At the maximum the farmers would be paid €51/kg removed nitrogen and €733 per kg removed phosphorus. The authors approach differs from this research in the sense that the authors of the paper did not include or examine any risk factors when using mussel farming as an abatement technique, which will be included in this study.

Hart et al. (2005) evaluate if mussel farming could function as a cost-effective method to improve water quality and also function as sustainable food production. The area in interest is the coast of Skagerrak and the production technique is limited to long-lined farming. The sewage plant in Lysekil, a community in the west coast of Sweden, releases 40 ton of nitrogen annually in the sea and due to EU-regulation 28 ton of nitrogen has to be abated, which would correspond to an annual production of 2800 ton of mussels.

The authors suggest that instead of paying the private producers of mussels the authorities should impose demands on tradable permits for those who emit pollution. The reason of not giving the mussel farmers payment to increase the production is the lack of mussel farmers. The extra payment would therefor not be an efficient way of increasing the abatement since the amount of mussel farms would lag behind. The authors do however comment that all pollution that is emitted into the coast is not derived from the sewage plant and that tradable permits for the plants may not be the optimal solution. The authors conclude with a statement that it is necessary with further investigation on mapping all pollution sources of nitrogen. To do so there must be over-boarder cooperation to reach the load targets of nutrients, which according to the authors would be the hardest part of creating a healthier water quality, not the abatement techniques in itself (Hart et al., 2005).

The difference between the Hart et al. (2005) and this study is first the geographic location; the authors concentrate on an increase in mussel farming in Skagerrak where this research will focus on the Baltic Sea. One additional difference is that the authors never examine if the mussel farms could be used as an offset for affected agents.

Unlike eutrophication management, offsets have been considered in climate policy where uncertain carbon sequestration has been of particular interest (e.g. Grönkvist et al. 2015). Grönkvist et al. (2015) discuss the uncertainty of carbon offsets and the possible future of CDM, Clean Development Mechanism, which is a mechanism under the Kyoto Protocol. The authors state that one explanation why there are so few projects in the CDM is the concern about non-permanence. The threat of non-permanence in carbon sinks is the risk for natural disturbance such as forest fires or human interventions. The authors refer to a paper published by secretariat to the UNFCCC when presenting solutions of the permanence concern. Possible solutions could be insurance of the forest or replacing the forest after e.g. a forest fire. The paper demonstrates the need of risk discount, even if it is in a different sector, but yet a biological element; it strengthens the hypothesis of this research.

Concerning the uncertainty when introducing new purification technology there is a lack of research of using mussel farming as an offset. However, Conte and Kotchen (2010) show that uncertainty of using carbon sinks as an offset could be significant. The authors result showed that the uncertainty decreased the price of carbon, which gives an indication that the uncertainty is significant. This implies that when introducing mussel farms as an offset, uncertainty and risk variables should be taken into account.

3. Theoretical framework

The theoretical framework in this research is minimization of costs for reaching nutrient load targets and the Lagrange multiplier method for solving the problem will then be used. The basis in Lagrange multiplier method is the maximizing or minimizing of an arbitrary multivariable function subject to one or more constraints defined on the same set as the objective function (Everett, 1963). The core idea in the method is to find values where the objective function is minimized and the constraints are met.

In this paper the Lagrange multiplier method is adapted to minimize the total abatement cost for nitrogen and phosphorus reductions to the Baltic Sea. This objective function equation (1) describes the cost minimization problem, *C*, for a specific country for reaching abatement targets on nitrogen and phosphorus, *N* and *P* respectively. Two classes of abatement options are included for each nutrient *E*, where *E=N, P*; mussel farming, M^E, and other measures A^E, which include, among other, increased cleaning at sewage treatment plants, and changes in management practices in agriculture. The total cost is the sum of all cost for other abatement techniques $C^E(A^E)$ and the cost for mussel farming $C^E(M^E)$. The constraint is that the sum of the abatement from other abatement techniques and mussel farming should be larger or equal to the abatement targets for phosphorus and nitrogen, R^E, that are set for each country by the Baltic Sea Helcom (2013).

$$\min_{A^E, M^E} C = \sum_{\mathrm{E}} [C^E(A^E) + C^E(M^E)] \qquad (1)$$

$$Subject\ to$$
$$A^E + M^E \geq R^E \quad for\ E = N, P \qquad (2)$$

The Lagrange equation (3) is expressed by the objective function and the constraints, which is written as

$$\mathcal{L} = \sum\nolimits_E C^E(A^E) + C^E(M^E) + \lambda^E(A^E + M^E - R^E) \qquad (3)$$

The lambda, λ^E, is an expression for the shadow price of abatement and is called the Lagrange multiplier. By differentiating eq. (3) with respect to other abatement techniques, A^E and mussel farming M^E the first order conditions are expressed in equation (4) and (5):

$$\frac{\partial \mathcal{L}}{\partial A^E} = \frac{\partial C^E}{\partial A^E} + \lambda^E = 0 \ \Rightarrow \frac{\partial C^E}{\partial A^E} = -\lambda^E \qquad (4)$$

$$\frac{\partial \mathcal{L}}{\partial M^E} = \frac{\partial C^E}{\partial M^E} + \lambda^E = 0 \ \Rightarrow \frac{\partial C^E}{\partial M^E} = -\lambda^E \qquad (5)$$

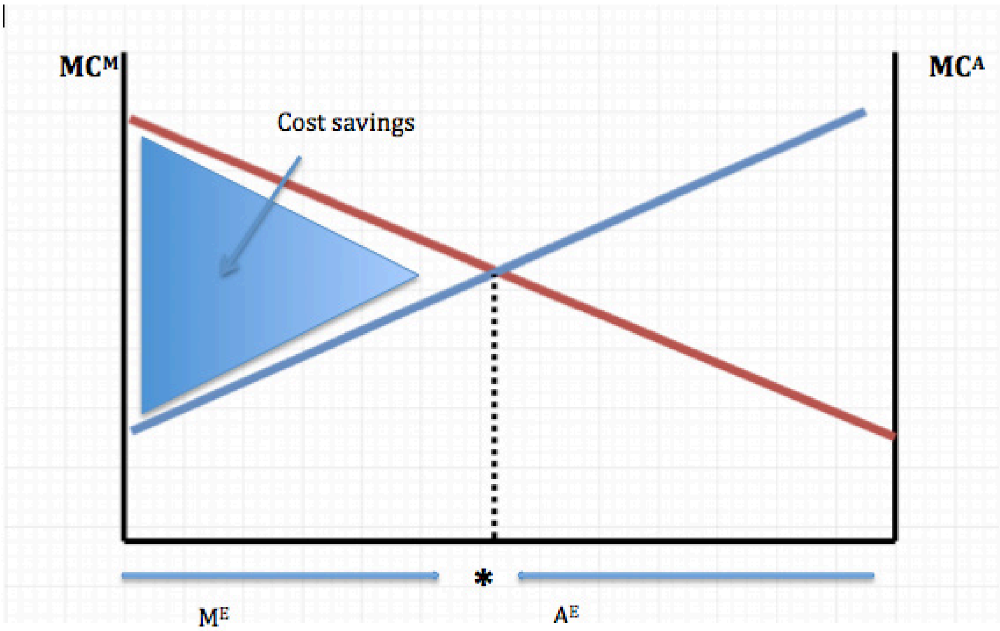
The first order conditions is then set to zero and then after rearrangement the expression of the first order condition is that the marginal value of other abatement techniques or mussel farming should be equal to the value of lambda, the shadow price. By combining equation (4) and (5) and setting them equal an expression for cost effectiveness is obtained.

$$\frac{\partial C^E}{\partial A^E} = \frac{\partial C^E}{\partial M^E} \qquad (6)$$

Expression (6) shows that in an optimal economic solution the marginal cost for other abatement techniques should be equal the marginal cost for mussel farming as an abatement technique. If the condition isn't fulfilled there are Pareto improvements to be done in the abatement regulation for the Baltic Sea. The expression describes that when abating an addition unit cost in other abatement techniques the marginal cost for mussel farming should be the same, in an efficient solution.

The optimization set up can also be described in graphical solution shown in Figure 1. The figure shows the hypothesis behind the abatement allocation in this paper. The marginal cost function are shown for both mussel farming, MC^M, and for other abatement techniques, MC^A. The optimal allocation of abatement for phosphorus and nitrogen is where the two marginal costs are equal, marked with *, which describes the same cost effectiveness as equation (6). The hypothesis is also that if the marginal cost for mussel farming is equal or lower than for other abatement techniques cost savings could be done. The blue area in the figure shows the cost savings from using mussel farms as abatement technique. The level of abatement for mussel farming is marked with M^E and the level for other abatement techniques is marked with A^E.

Figure 1. Graphic illustration of cost effective allocation of abatement



Source; Own illustration

So far, some assumptions are made when deriving the model for optimal abatement allocation in the Baltic Sea, which is that the precise treatment capacity and hence the abatement cost for mussel farming is without uncertainty. In reality, a new abatement technology based on a biological organism is uncertain because of stochastic weather conditions. When not controlling for uncertainty the revenue from using mussel farming as an offset could potentially be overestimated. This however is based on the assumption that the purchaser of the offset is risk averse, which implies that there is a will to reduce the level of risk (The Economic Times, u.d.). Gren et. al. (2008) state that the uncertainty of cleaning cost is depending on mussel's growth rate, sales options for the mussel and formulation of nutrient load targets in the Baltic Sea. There are incentives to include an uncertainty discount if the purchaser of the offset is risking penalty if not fulfilling the abatement targets due to the potential uncertainties of mussel farming. An uncertainty discount accounts for the risk of penalty for the purchaser. The level of an uncertainty discount would be based on the trade off between the costs of securing more assurance and the cost of being out of fulfilment of abatement (Kim, McKarl 2009).

Due to inadequate data on how to model a risk discount for mussel farming a model for land-based carbon sequestration is adapted. Kim and McKarl (2009) present a model for risk discount where the discount appears in the abatement constraint. It is derived from the standard statistical confidence interval where the creditable amount is a reduction from the expected value, which is based on the standard error of the abatement of mussel farming. The uncertainty discount contains a perception towards risk, RA, and a measure of risk as the standard deviation in abatement. The RA is expressed as a predetermined confidence interval in relation to the mean abatement, which can be found in a one tailed Z table. The standard deviation is measured as the coefficient of variation, cv^E, times the mean abatement, M^E, where

$$cv^E = \frac{standard\ deviation^E}{mean^E} \qquad (7)$$

The coefficient of variation is a normalized standard deviation and describes the share of the spread from the mean. The abatement constraint in equation (2) is then rewritten as

$$A^E + M^E - RAcv^E M^E \geq R \qquad (8)$$

The Lagrange set up is shown in expression (10) and the first order conditions follow in equation (11)-(13).

$$\mathcal{L} = \sum_{E}^{n} C^E(A^E) + C^E(M^E) + \lambda^E(A^E + (1 - RAcv^E)M^E - R) \qquad (10)$$

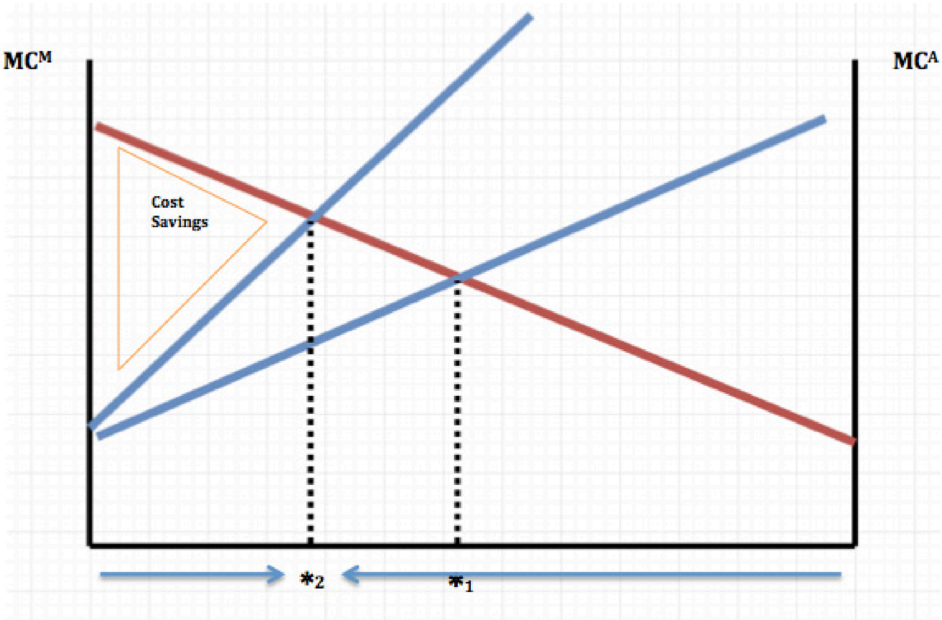
$$\frac{\partial \mathcal{L}}{\partial A^E} = \frac{\partial C^E}{\partial A^E} + \lambda^E = 0 \;\Rightarrow \frac{\partial C^E}{\partial A^E} = -\lambda^E \qquad (11)$$

$$\frac{\partial \mathcal{L}}{\partial M^E} = \frac{\partial C^E}{\partial M^E} + \lambda^E(1 - RAcv^E) = 0 \;\Rightarrow \frac{\partial C^E}{\partial M^E} = -\lambda^E(1 - RAcv^E) \qquad (12)$$

$$\frac{\partial C^E}{\partial A^E} = \frac{\frac{\partial C^E}{\partial M^E}}{(1 - RAcv^E)} \qquad (13)$$

The added uncertainty discount in the constraint for the optimization problem is also shown graphically in figure 2. The uncertainty discount results in an upward rotation of the marginal cost function for mussel farming. The level of abatement will, due to the rotation of the function, be changed. The economic optimal level of abatement for mussel farming will decrease and economic optimal level of other abatement techniques will increase as visible in the graph. The saved cost, the framed area in the graph is reduced compared to the saved costs in figure 1 where there were no risk discounts included.

Figure 2. Graphic illustration of cost effective allocation of abatement including uncertainty discount



Source: Own illustration

4. Data description

The Baltic Sea is divided into three different basins due to significant differences in the aquatic environment, which affects the potential of mussel farming. The basins differ in salinity, which affects the growth of organisms. Due to lower salinity in the north Baltic Sea the vegetation and organisms have harder so survive than in the south Baltic Sea (Havet, u.d.b). Bothnian Sea and Bothnian Bay, the basins above Åland, will be excluded because of the low growth rate of organisms and vegetation and therefor mussel farming is not an option in that area.

The categorization of the countries that have coastline in the Baltic Sea is shown in table 1 and is needed due to lack of data on mussel farming in each country. There are assumptions made that if the country has coastline to more than one of the three basins in the Baltic Sea the country will chose to set their mussel farms on in the basin that provides the largest yield of mussels. Kaliningrad is, as the map in fig 3. of the Baltic Sea shows, a Russian enclave that is located between Poland and Latvia. If the result shows that it would be more beneficial to locate their mussel farms along the coastline of Kaliningrad than the Russian coastline an assumption is made that the country will chose to do so.

The countries that has coastline to the Baltic Sea are divided into three categories, Kattegat, South Baltic Proper and North Baltic Proper, which is shown in table 1.

Table 1. Country classification on different Baltic Sea basins

Country	Basin
Sweden	Kattegat
Poland	South BP
Finland	North BP
Denmark	Kattegat
Germany	South BP
Estonia	North BP
Latvia	South BP
Lithuania	South BP
Russia	North BP
Kaliningrad	South BP

4.1 Cost of mussel farming

Table 2 presents data of different mussel farming attempts that has been done in the Baltic Sea region. The table shows that there is a significant difference in yield between the basins in the Baltic Sea. The mussel farm in Kattegat could produce more than twice as much mussel than in the North Baltic Proper in the same time frame.

BalticSea2020 (2012) present some attempts on mussel farming in the Baltic Sea. The results from a farming attempt in Kalmarsund will be partially used for the calculations in this paper. Odd Lindahl (u.d.) in the Academy of Science has collected results from attempts in both Åland and Kattegat and his result includes data on yield and rotation length on mussel farming. Gren et al. (2009) contributed with data on estimated content of nutrients per hectare and the estimated cost of producing mussels. The different basins in the Baltic Sea have different cost functions for mussel farming and Gren et.al (2009) show that the nutrient content in mussel farms differs depending on the basins.

The mussel farming attempt in Kattegat, presented by Lindahl (u.d.) and the cost per ton mussel from Gren et.al (2009) is reported in ranges. The attempts in Åland and Kalmarsund on the other hand were only reporting an exact result. It is therefore assumed that the exact results are the mean of field experiment in yield and nutrient (N, P) content and a range is made with the same distribution as the ranges provided by Lindahl (u.d.), see table 2.

To calculate the total cost per ton mussels in the different basins will be shown in table 2. The total cost per ton mussel is determined by the yield in the basin combined with the cost per ton mussel. The range in the total cost of mussel farming per hectare is determined by taking the yield multiplied with the lower bound in the cost range per ton mussel and the higher bound is determined by multiplying the yield and the higher bound in the cost per ton mussel.

Table 2. Cost of mussel farming

Basin	Year of growth	Yield per hectare (ton)	Cost (€) per ton mussel	Total cost (€) per hectare
Kattegatt[1] (West Coast)	1-1.5	200-300	80-100	16000-30000
North Baltic Proper[1] (Åland)	2	130-190	330-540	42900-102600
South Baltic Proper[2](Kalmarsund)	2	120-180	180-210	21600-37800

[1]Lindahl (u.d.), Gren et.al (2009)
[2] BalticSea2020 (2012), Gren et.al (2009)

Since the abatement targets for the Baltic Sea is set in the entity ton phosphorus and ton nitrogen there has to be conversion of the costs from total cost per ton or hectare mussel to the total cost per kilo or ton nutrient. Table 3 shows the total cost per ton and kilo Nitrogen and the cost range expressed in both Euro and in the Swedish crown. The currency transformation is necessary since the sources of the data uses different currencies and to interpret the final result the monetary values would understandably have to be in the same currency. The currency transformation occurred 18th of April 2016 and the Forex Bank was used for currency information. 1 Euro was converted to 9,66 SEK (Forex, 2016). The cost per ton nitrogen is determined by the total cost (€) of mussel farming shown in table 2 divided with the estimated value of nitrogen content per hectare. The result is presented in an interval and all possible outcomes calculated from the total cost for mussel farming and the estimated value of nitrogen per hectare are within the interval. The data on nutrient content per hectare mussel is derived from Gren et.al (2009).

Table 3. Cost calculations of nitrogen

Basin	Total cost (€) per hectare[1]	Ton N per hectare[2]	Cost SEK per kg N
Kattegat (West Coast)	16000-30000	2.4-3.6	42.5-120.8
North Baltic Proper (Åland)	42900-102600	1.04-1.56	265.7-953.4
South Baltic Proper (Kalmarsund)	21600-37800	1.44-2.16	96.6-254.1

[1]Table 2
[2]Gren et.al (2009)

Same calculations where done for phosphorus which shows in table 4.

Table 4. Cost calculations of Phosphorus

Basin	Total cost (€) per hectare[1]	Ton P per hectare[2]	Cost SEK per kg P
Kattegat (West Coast)	16000-30000	0.18-0.24	644-1610
North Baltic Proper (Åland)	42900-102600	0.09-0.11	3767-11012
South Baltic Proper (Kalmarsund)	21600-37800	0.10-0.14	1491-3651

[1]Table 2
[2]Gren et.al (2009)

4.2 Cost of other abatement techniques

To determine if mussel farming could be an abatement alternative the cost function for other abatement techniques have to be determined. This must be done to derive the optimal allocation of abatement of mussel farming and other abatement techniques used in the Baltic Sea. From the cost function the marginal cost function will be derived to see if mussel farming satisfices the first order condition in the optimization problem described in section 3. Mussel farming will only be interesting to use as an offset if the marginal cost is equal or lower than the marginal cost for other abatement technique in the Baltic Sea, as described in section 3.

It is assumed that the cost functions for other abatement techniques of nitrogen respective phosphorus are determined by;

$$C(N) = \alpha N^2 \qquad (14)$$

$$C(P) = \beta P^2 \qquad (15)$$

The marginal cost function is determined by taking the first derivative of the cost function for nitrogen respective phosphorus and is given by;

$$\frac{dC}{dN} = 2\alpha N = MC_N \qquad (16)$$

$$\frac{dC}{dP} = 2\beta P = MC_P \qquad (17)$$

The coefficients, *beta* and *alfa*, in the cost functions for nitrogen and phosphorus for the different countries and the basin the country is categorized to are presented in table 5 below. The data of the cost functions for other abatement techniques in the Baltic Sea are obtained from the Gren et al. (2014) .

Table 5. Coefficients in cost functions for other abatement

Country	**Basin**	**Coefficient** α^1	**Coefficient** β^1
Sweden	Kattegat	3.577	1576.631
Poland	South BP	0.347	94.01
Finland	North BP	5.648	2089.229
Denmark	Kattegat	0.293	1945.179
Germany	South BP	4.946	11 836.62
Estonia	North BP	1.274	1394.426

Latvia	South BP	3.61	1021.817
Lithuania	South BP	0.776	511.138
Russia	North BP	2.904	340.171
Kaliningrad	South BP	2.904	340.171

[1]Gren et al. (2014)

4.3 Validity

To determine if the result in section 5 is valid coastline for each country is presented in table 6 (WorldbyMap, 2015). Data for Kaliningrad's coastline is derived from Bird (2010).

Table 6. Coastline of the Baltic Sea

Country	Length (km)
Sweden	3218
Poland	440
Finland	1250
Denmark	7314
Germany	2389
Estonia	3794
Latvia	498
Lithuania	90
Russia	839
Kaliningrad Russia	220

The results of the calculations with the data described in section above follow in section 5.

4.4 Abatement calculations mussel farming without uncertainty discount

The marginal cost for other abatement techniques for phosphorus and nitrogen is as equation (16) and (17) shows not linear and is depending on the amount of nutrient. To determine the marginal cost for other abatement technique, the total load of nitrogen and phosphorus in the Baltic Sea will be presented with the reduction requirement for each country in both relative and precise terms in thousand ton in table 7. The data of the loads are derived from the department of SLU (2016) and abatement requirement is derived from Copenhagen ministerial declaration 2013 (2013).

Table 7. Nutrient load and reduction requirement

Country	**Basin**	**N Load t(t)**	**P Load t(t)**	**% Reduction target N**	**% Reduction target P**	**Abatement requirement N t(t)**	**Abatement requirement P t(t)**
Sweden	**Kattegat**	74	1.6	0.29	0.34	21.46	0.544
Poland	**South BP**	318	22	0.29	0.64	92.22	14.08
Finland	**North BP**	49	1.7	0.08	0.25	3.92	0.425
Denmark	**Kattegat**	44	1.1	0.3	0.31	13.2	0.341
Germany	**South BP**	46	0.5	0.27	0.45	12.42	0.225
Estonia	**North BP**	56	1.6	0.05	0.18	2.8	0.288
Latvia	**South BP**	44	3	0.25	0.19	11	0.57
Lithuania	**South BP**	93	3.5	0.26	0.66	24.18	2.31
Russia	**North BP**	83	4	0.08	0.37	6.64	1.48
Kaliningrad Russia	**South BP**	83	4	0.08	0.37	6.64	1.48

To determine if mussel farming has a lower marginal cost than other abatement techniques the marginal cost when the country uses other abatement techniques to abate the full requirement is used. This gives the highest marginal cost of other abatement measures, and mussel farming is of interest only if its marginal cost is below this level. The maximum MC for other abatement is derived by taking the abatement requirement and putting in it the marginal cost function for nitrogen respective phosphorus shown in equation (18) and (19). The results of the calculations are shown in table 8. The table shows the marginal cost for the different countries when the country is abating nitrogen and phosphorus as required from Helcom Ministerial Declaration (2013).

$$\frac{dC_{Country\,X}}{dN} = 2\alpha_{country\,X} * N_{requirement\,Country\,X} = MC_{Country\,X} \tag{18}$$

$$\frac{dC_{Country\,X}}{dP} = 2\beta_{country\,X} * P_{requirement\,Country\,X} = MC_{Country\,X} \tag{19}$$

Table 8. Marginal cost fulfilling abatement requirement with A^E

Country	**Basin**	**MC full abatement Nitrogen (SEK/kg)**	**MC full abatement Phosphorus (SEK/kg)**
Sweden	Kattegat	154	1715
Poland	South BP	64	2647
Finland	North BP	44	1776
Denmark	Kattegat	8	1327
Germany	South BP	123	5327
Estonia	North BP	7	803
Latvia	South BP	79	1165
Lithuania	South BP	38	2362
Russia	North BP	39	1007
Kaliningrad	South BP	39	1007

The cost efficient level of abatement for nitrogen and phosphorus by mussel farms in each country that has coastline to the Baltic Sea is determined by the condition for cost effectiveness as shown by equation (20) and (23) respectively. As mentioned in section 3 it is assumed that the marginal cost for mussel farms is constant, which makes calculations of abatement levels for mussel farms achievable. Equation (20) and (23) describe the deterministic version from section 3, equation (6) where the marginal cost for mussel farming is equal the marginal cost for other abatement in an optimal solution. With some rearrangement it can be solved for level of nitrogen for other abatement techniques, equation (21) and optimal level for phosphorus, equation (23). The cost efficient level of mussel farming is determined in equation (22) and (25) for nitrogen respective phosphorus by subtracting the level of other abatement techniques from the required level of abatement for the country of interest.

$$MC_{mussel\ farm\ basin\ X} = 2\alpha N_{Other\ Abatement} \qquad (20)$$

$$N_{Other\ Abatement} = \frac{MC_{mussel\ farm\ basin\ X}}{2\alpha} \qquad (21)$$

$$N_{Mussel\ Farm} = Abatement\ requirement_N - N_{Other\ Abatement} \qquad (22)$$

$$MC_{mussel\ farm\ basin\ X} = 2\beta P_{Other\ Abatement} \qquad (23)$$

$$P_{Other\ Abatement} = \frac{MC_{mussel\ farm\ basin\ X}}{2\beta} \qquad (24)$$

$$P_{Mussel\ Farm} = Abatement\ requirement_P - P_{Other\ Abatement} \qquad (25)$$

5. Simulation and Result

5.1 Abatement allocation without uncertainty discount

The cost effective abatement level of nitrogen and phosphorus with mussel farming for each country is presented below. It is assumed that each country can only credit abatement for nitrogen *or* phosphorus. This implies that the marginal cost is carried out by abating phosphorus *or* nitrogen, and cannot be shared between the nutrients. The countries that have a larger marginal cost of mussel farming than for other abatement techniques is not included in the table since they would not include mussel farming as an abatement measure. As mentioned in section 3 mussel farming would only be interesting as an offset if the marginal cost is lower than for other abatement techniques in the country of interest.

When estimating the cost effective levels of abatement of nitrogen and phosphorus by mussel farming and other abatement techniques the marginal costs were equalized. The level of abatement with mussel farming was determined by applying equation (22) and (25) for nitrogen and phosphorus. To determine the level of mussel farm in hectare the level of nutrient reduction in ton was divided with the mean abatement per hectare for each nutrient and country. The cost saved by implementing mussel farms is determined by the difference in marginal cost for mussel farm and other abatement as illustrated in figure 1.. The percentages saving for each country are calculated by dividing the cost savings by implementing mussel farms by the total cost of abatement without mussel farming.

The result for nitrogen shows that Sweden and Germany would benefit from introducing mussel farms. In this deterministic case Sweden would abate 15.52 thousand ton nitrogen with mussel farms, which correspond to 5000 hectare of mussel farms. Germany would abate 2.65 thousand ton nitrogen with mussel farming which correspond to almost 1500 hectare of mussel farms. Sweden would save a significant amount, 52 percentages while Germany would only save perceptible amount of 5 percentages. There is a significant difference between the two countries allocation of abatement. In Sweden the most cost effective solution is that mussel farms abate the largest part of the reduction requirement while in Germany it is rather the opposite.

When estimating the allocation of abating phosphorus, Sweden, Poland, Denmark, Germany and Lithuania showed positive cost savings from introducing mussel farms as an offset. The cost efficient allocation for Sweden is that mussel farming accounts for a larger share of abatement than other abatement techniques and the cost savingfrom introducing mussel farms as an offset is 39 percentages. Poland will abate 6.15 thousand ton nitrogen by using mussel farms and will save 19 percentage in costs. The total cost savings in mill SEK for Poland is significantly larger than for any other country in the table but can be explained by the reduction requirement for phosphorus also is significantly larger for Poland than for the other countries.

Germany will use mussel farming in a significant larger scale than other abatement techniques, according to the result. Other abatement is estimated to 60 ton and mussel farms to 165 ton phosphorus. This would result in a decrease in total cost by 52 percentages. Lithuania's level of mussel farming in a cost efficient allocation is estimated 850 ton phosphorus while for other abatement techniques the level corresponds to 1460 ton. This would result in total cost savings by 27 percentages.

Table 9. Cost efficient allocation and cost savings from introducing mussel farms for abating nitrogen and phosphorus

Nitrogen

Country	Basin	Abatement A^N t(t) N	Abatement M^N t(t) N	Hectare M^N	Cost savings mill SEK	Percentage cost saving (%)
Sweden	**Kattegat**	5.94	15.52	5173	861.5	52
Germany	**South BP**	9.77	2.65	1472	34.9	5

Phosphorus

Country	Basin	Abatement A^P t(t) P	Abatement M^P t(t) P	Hectare M^P	Cost savings mill SEK	Percentage cost saving (%)
Sweden	**Kattegat**	0.2	0.344	1638	182	39
Poland	**South BP**	7.93	6.15	51250	3556	19
Denmark	**Kattegat**	0.17	0.171	814	60	27
Germany	**South BP**	0.06	0.165	1375	311	52
Lithuania	**South BP**	1.46	0.85	7083	731	27

5.2 Mussel farming with uncertainty discount

So far the calculations and the result for nitrogen and phosphorus abatement with mussel farming has been without uncertainty. In this section the same calculations are done but now with included uncertainty discount, presented in section 3.

Kim and Carl (2009) recommend the use of90 % probability level when calculating uncertainty discount. In the subsequent simulation there will be calculations including probability level of 90, 95 and 99 percentages to test the results. The probability level is determined by how risk averse the decision maker is, e.g. if a decision maker request a probability level of 95 percentage he or she demands that 95 percentage of the outcome is within the abatement range of mussel farms. Hence, the larger probability the larger uncertainty discount. A 95 percentage confidence interval is used for calculating *CV* and is estimated to 0.1 for all basins since it is assumed that the spread in each interval of nutrient content per hectare is equal. *RA* is calculated by using a one tailed Z-table. For probability of 90 percentages, *RA* is equal to 1,28. For probability of 95 percentages, *RA* is equal to 1,64 and for 99 percentages *RA* is equal to 2.33.

The countries that revealed zero result in section 5.1 are not included in the tables below. The uncertainty discount is calculated so that the marginal cost of mussel farm would increase when including the uncertainty factor. Therefor the countries that had a negative result without uncertainty discount when including mussel farming as an abatement technique will display a more negative result, which implies that mussel farming as abatement is still not an option for those countries.

5.2.1 Estimates of nitrogen

In table 10 uncertainties discount for nitrogen is estimated for Sweden and Germany with a probability of 95 percentages. The uncertainty discount in the unit of thousand ton mussel is calculated by multiplying CV, RA and the level of mussel farming with no uncertainty discount, which is in line with section 3 where the uncertainty estimation is described.

The marginal cost for mussel farming when including uncertainty is estimated by applying equation (13) in section 3 on the data set. The remaining calculations are in line with the calculations done without uncertainty discount in section 5.1.

The result shows that when including uncertainty the level of abatement with mussel farm decreases compared to the result without uncertainty discount. In addition, the total cost savings and the percentage savings by implementing mussel farms, naturally, decrease as well.

For Sweden the percentage saving is estimated to 47 percentages at a 90 percentage probability level. For 95 the corresponding result is 45 percentages and for 99 probability level the result is a percentage savings of 41 of implementing mussel farms.

For Germany the result shows that the percentage savings are negligible. For a probability level of 95% the savings only correspond to one percentage. Noteworthy, when estimating the level of mussel farming at a probability level of 99 percentages Germany would not benefit at all. In a cost efficient allocation, the total abatement would be implemented by other abatement technique.

Table 10. Cost effective abatement allocation of nitrogen and cost savings with probability level 90, 95 and 99 %

90%

Country	Basin	Uncertainty discount	New MC M^N (SEK/kg)	Abatement A^N t(t) N	Abatement M^N t(t) N	Hectare M^N	Cost savings mill SEK	Percentage savings (%)
Sweden	**Katte gatt**	0.128	49	6.81	14.65	4882	771	47
Germany	**South BP**	0.128	111	11.20	1.22	678	7	1

95%

Country	Basin	Uncertainty discount	New MC M^N (SEK/kg)	Abatement A^N t(t) N	Abatement M^N t(t) N	Hectare M^N	Cost savings mill SEK	Percentage savings (%)
Sweden	**Katte gatt**	0.164	51	7.11	14.35	4785	740	45
Germany	**South BP**	0.164	116	11.68	0.74	410	3	0.4

99%

Country	Basin	Uncertainty discount	New MC M^N (SEK/kg)	Abatement A^N t(t) N	Abatement M^N t(t) N	Hectare M^N	Cost savings mill SEK	Percentage savings (%)
Sweden	**Kattegatt**	0.233	55	7.75	13.71	4572	676	41
Germany	**South BP**	0.233	126	12.42	-	-	-	-

5.2.2 Estimates of phosphorus

The calculations of allocation of abatement for phosphorus are in line with the calculations done in section 5.2.1 but with data for phosphorus understandably.

The estimates show that Germany would benefit the most of introducing mussel farms, a percentage savings of 46 percentages with a probability of 0.90. Poland would have the largest savings in absolute terms, which is explained by their sizeable abatement requirements.

When preferring a 99 percentages probability level Poland and Lithuania have negligible savings in percentage terms.

Table 11. Cost effective abatement allocation of phosphorus and cost savings with probability level 90, 95 and 99 %

90%

Country	Basin	Uncertainty discount	New MC M^P (SEK/kg)	Abatement A^P t(t) P	Abatement M^P t(t) P	Hectare M^P	Cost savings mill SEK	Percentage savings (%)
Sweden	**Kattegat**	0.128	739	0.23	0.31	1475	151	32
Poland	**South BP**	0.128	1710	9.09	4.99	41550	2336	13
Denmark	**Kattegat**	0.128	739	0.19	0.15	720	44	20
Germany	**South BP**	0.128	1710	0.07	0.15	1273	276	46
Lithuania	**South BP**	0.128	1710	1.67	0.64	5312	208	8

95%

Country	Basin	Uncertainty discount	New MC M^P (SEK/kg)	Abatement A^P t(t) P	Abatement M^P t(t) P	Hectare M^P	Cost savings mill SEK	Percentage savings (%)
Sweden	**Kattegat**	0.164	770	0.24	0.30	1427	142	30
Poland	**South BP**	0.164	1783	9.49	4.59	38286	1984	11
Denmark	**Kattegat**	0.164	770	0.20	0.14	681	40	18
Germany	**South BP**	0.164	1783	0.08	0.15	1247	265	44
Lithuania	**South BP**	0.164	1783	1.74	0.57	4711	164	6

99%

Country	Basin	Uncertainty discount	New MC M^P (SEK/kg)	Abatement A^P t(t) P	Abatement M^P t(t) P	Hectare M^P	Cost savings mill SEK	Percentage savings (%)
Sweden	**Kattegat**	0.233	840	0.27	0.28	1322	122	26
Poland	**South BP**	0.233	1944	10.34	3.74	31175	1315	7
Denmark	**Kattegat**	0.233	840	0.22	0.13	596	31	13
Germany	**South BP**	0.233	1944	0.08	0.14	1191	242	40
Lithuania	**South BP**	0.233	1944	1.90	0.41	3404	85	3

5.3 Determine the realism of the results

The results of level of mussel farming with and without uncertainty discount are not applicable if there are no water spaces for each country to acquire for mussel farming. It is assumed that mussel farms can at it maximum be farmed 300 meters from the coastline, which implies that some mussel farms could have to be implemented in shore protection areas. This implies, given the coastline length in section 4.3 that no countries coastline would be limiting the implementation of mussel farming.

6. Scenario analysis

In this section results from a policy change is presented. From the previous assumption that agents can only count for abating nitrogen *or* phosphorus when implementing mussel farms it is now assumed that the regelation allows for counting *both* nitrogen and phosphorus, known as double dipping (e.g. Woodward, 2011). This implies that the cost for mussel farming could be shared between phosphorus and nitrogen and therefor the result from previous section would be changed. In the simulation of the result in this section there is an assumption made that the production cost is assigned with the weight of 0.5 for phosphorus and respective nitrogen. The estimates below are calculated with and without uncertainty discount. The column *D/ND* defines if the country is depending or not depending on a policy chance to be beneficial of introducing mussel farms.

6.1 Partial cost for nitrogen and phosphorus without uncertainty discount

The results show that when allowing for double dipping additional countries with coastline to the Baltic Sea would benefit from introducing mussel farms as abatement. For nitrogen Poland and Latvia the cost savings are small. The percentage saving for Sweden increased to 74 percentages when only labelling half of the marginal cost to the nutrient and to 37 percentages for Germany.

The estimates for phosphorus show that Latvia and Kaliningrad enter the table with significant cost savings. Latvia would save 26 percentages and Kaliningrad would save 18 percentages.

Table 12. Cost effective abatement allocation nitrogen and phosphorus under double dipping

Nitrogen							
Country	**Basin**	**Abatement A^N t(t) N**	**Abatement M^N t(t) N**	**Hectare M^N**	**Cost savings mill SEK**	**Percentage saving (%)**	**D/ ND**
Sweden	**Kattegat**	2.97	18.49	6163	1223	74	ND
Poland	**South BP**	69.60	22.62	12569	178	6	D
Germany	**South BP**	4.88	7.54	4187	281	37	ND
Latvia	**South BP**	6.69	4.31	2395	67	8	D

Phosphorus							
Country	**Basin**	**Abatement A^P t(t) P**	**Abatement M^P t(t) P**	**Hectare M^P**	**Cost savings mill SEK**	**Percentage saving (%)**	**D/ ND**
Sweden	**Kattegat**	0.10	0.44	2104	308	66	ND
Poland	**South BP**	3.97	10.11	84292	9618	52	ND
Denmark	**Kattegat**	0.08	0.26	1230	130	57	ND
Germany	**South BP**	0.03	0.19	1613	443	74	ND
Latvia	**South BP**	0.36	0.21	1710	86	26	D
Lithuania	**South BP**	0.73	1.58	13173	1612	59	ND
Kaliningrad Russia	**South BP**	1.10	0.38	3202	132	18	D

6.2 Partial cost for nitrogen with uncertainty discount

The same weight of 0.5 is given to the estimates including uncertainty discount. The result shows that Poland and Latvia would benefit. Sweden and Germany save more in absolute and percentage terms since the burden of cost is now shared. The greater probability level, the smaller savings which is intuitive.

Table 13. Cost effective abatement allocation nitrogen with uncertainty under double dipping

90%

Country	*Basin*	*Uncertainty discount*	*New MC M^N (SEK/kg)*	*Abatement A^N t(t) N*	*Abatement M^N t(t) N*	*Hectare M^N*	*Cost savings mill SEK*	*Percentage savings (%)*	*D/ ND*
Sweden	**Kattegatt**	0.128	24	3.41	18.05	6018	1170	71	ND
Germany	**South BP**	0.128	55	5.60	6.82	3789	231	30	ND
Poland	**South BP**	0.128	55	79.81	12.41	6893	53	2	D
Latvia	**South BP**	0.128	55	7.67	3.33	1849	39	9	D

95%

Country	**Basin**	**Uncertainty discount**	**New MC M^N (SEK/kg)**	**Abatement A^N t(t) N**	**Abatement M^N t(t) N**	**Hectare M^N**	**Cost savings mill SEK**	**Percentage savings (%)**	**D/ ND**
Sweden	**Kattegatt**	0.164	25	3.55	17.91	5969	1151	70	ND
Germany	**South BP**	0.164	58	5.84	6.58	3655	215	28	ND
Poland	**South BP**	0.164	58	83.25	8.95	4973	28	1	D
Latvia	**South BP**	0.164	58	8.00	3.00	1666	32	7	D

99%

Country	**Basin**	**Uncertainty discount**	**New MC M^N (SEK/kg)**	**Abatement A^N t(t) N**	**Abatement M^N t(t) N**	**Hectare M^N**	**Cost savings mill SEK**	**Percentage savings (%)**	**D/ ND**
Sweden	**Kattegatt**	0.233	28	3.87	17.59	5862	1111	67	ND
Germany	**South BP**	0.233	63	6.37	6.05	3363	182	24	ND
Poland	**South BP**	0.233	63	90.74	1.46	812	1	0.02	D
Latvia	**South BP**	0.233	63	8.72	2.28	1266	18	4	D

6.3 Partial cost for phosphorus with uncertainty discount

Latvia and Kaliningrad depend on a double dipping policy to benefit from mussel farming as abatement, but obtain only negligible cost savings. The countries that don't depend on a policy change to benefit from introducing mussel farming have, as expected, even more beneficial results than in the result where double dipping was not allowed.

Table 14. Cost effective abatement allocation phosphorus with uncertainty under double dipping

90%

Country	Basin	Uncertainty discount	New MC M^P (SEK/kg)	Abatement A^P t(t) P	Abatement M^P t(t) P	Hectare M^P	Cost savings mill SEK	Percentage savings (%)	D/ND
Sweden	**Kattegat**	0.128	369	0.12	0.43	2033	287	62	ND
Poland	**South BP**	0.128	855	4.55	9.53	79441	8542	46	ND
Denmark	**Kattegat**	0.128	369	0.09	0.25	1172	118	26	ND
Germany	**South BP**	0.128	855	0.04	0.19	1574	422	70	ND
Latvia	**South BP**	0.128	855	0.42	0.15	1264	24	7	D
Lithuania	**South BP**	0.128	855	0.84	1.47	12281	1110	41	ND
Kaliningrad	**South BP**	0.128	855	1.26	0.22	1862	17	2	D

95%

Country	Basin	Uncertainty discount	New MC M^P (SEK/kg)	Abatement A^P t(t) P	Abatement M^P t(t) P	Hectare M^P	Cost savings mill SEK	Percentage savings (%)	D/ND
Sweden	**Kattegat**	0.164	385	0.12	0.42	2009	280	60	ND
Poland	**South BP**	0.164	892	4.74	9.34	77810	8195	44	ND
Denmark	**Kattegat**	0.164	385	0.10	0.24	1152	114	50	ND
Germany	**South BP**	0.164	892	0.04	0.19	1561	415	69	ND
Latvia	**South BP**	0.164	892	0.44	0.13	1114	18	5	D
Lithuania	**South BP**	0.164	892	0.87	1.44	11981	1057	39	ND
Kaliningrad	**South BP**	0.164	892	1.31	0.17	1411	10	1	D

99%

Country	Basin	Uncertainty discount	New MC M^P (SEK/kg)	Abatement A^P t(t) P	Abatement M^P t(t) P	Hectare M^P	Cost savings mill SEK	Percentage savings (%)	D/ND
Sweden	**Kattegat**	0.233	420	0.13	0.41	1956	266	57	ND
Poland	**South BP**	0.233	972	5.17	8.91	74254	7463	40	ND
Denmark	**Kattegat**	0.233	420	0.11	0.23	1110	106	47	ND
Germany	**South BP**	0.233	972	0.04	0.18	1533	401	69	ND
Latvia	**South BP**	0.233	972	0.48	0.09	787	9	3	D
Lithuania	**South BP**	0.233	972	0.95	1.36	11327	945	35	ND
Kaliningrad	**South BP**	0.233	972	1.43	0.05	428	1	0,1	D

7. Discussion and Conclusion

Implementing mussel farms as an offset in mitigating eutrophication in the Baltic Sea has shown to be beneficial for several countries that have coastline to the sea. When including an uncertainty discount it only changed the level of mussel farming for those countries that were benefitting from including mussel farms without uncertainty. The uncertainty discount only resulted in that Germany would not benefit for abating nitrogen at a 99 percentage probability level. This indicates that the result is reasonably robust to uncertainty discounting.

Assuming a policy change where double dipping is allowed did, as expected, make it beneficial for more countries to introduce mussel farming. The result also showed that Poland and Latvia would benefit from introducing mussel farms for nitrogen abatement. For phosphorus abatement, also Latvia and Kaliningrad would benefit from introducing mussel farming.

When considering the abatement requirement it is noteworthy that Poland is assigned a large share, which could mean that the share of mussel farming for Poland is expected to be large. However the marginal cost for other abatement for Poland is so low that the share of mussel farms was kept at a relatively low in the estimations.

One could assume that Denmark would be a beneficial country since the country is located with a coastline to Kattegat and the result shows that the country would benefit from crediting phosphorus from the mussel farming. For nitrogen, mussel farming would not be beneficial despite the favourable location. This could be explained by the low marginal cost for other abatement techniques for nitrogen in the country.

A conclusion of the result is that for mussel farming to be beneficial and for the farms to be used as an offset there are two elements that need to be fulfilled. The aquatic environment needs to be in line with the mussels' growth requirements and the abatement cost for other techniques have to be relatively low.

One assumption in the research was to not include any potential profit from selling the mussels after harvesting. The assumption could potentially be disputed. Implementing mussel farms as recommended for the countries with positive result would result in a large pile of mussel if they are not sold or used for other purposes. The basic principle of implementing mussel farms as an offset of eutrophication is that the mussels need to be harvested. The potential of selling the mussel for human consumption could be questioned since the growth of the mussel is reduced but using mussels from the Baltic Sea as animal feed could be an alternative to investigate.

In addition, assuming that the marginal cost for mussel farms is constant could be disputed. There are reasons to believe that the larger biomass of mussels would require larger farms and imply larger marginal cost since it would probably demand more transportation and equipment.

In conclusion, the result in this study depends on assumptions and the result can change significantly when the assumptions is changed. However, the different estimates show that mussel farming could compete with other abatement techniques to achieve the abatement requirement for phosphorus and nitrogen in the Baltic Sea.

One could ponder upon if the abatement requirement for each country is feasible given the economic situation in respectively country. Poland is a heavy emitter of nutrients in the Baltic Sea and therefor has large abatement requirements.. Setting a target that a country cannot achieve creates tensions between the country and the eutrophication in the sea would still be, and still are, a problem.

Data from the mussel farming attempts that are used in this study could potentially suffer from reporting bias. The reason is the researchers' eventual positive attitude towards mussel farming, which may result in relatively low cost estimates. For the result of this paper to have fully internal validity more data on mussel farming in the Baltic Sea are desirable. The result in this study can however be used as an indicator that mussel farming could function as an offset in mitigating eutrophication in the Baltic Sea for several countries, also under conditions of uncertain abatement.

References

Agricultural and rural convention 2020. 2014. *Factory farming makes Baltic Sea one of the world's most polluted*. http://www.arc2020.eu/2014/06/factory-farming-made-the-baltic-sea-one-of-the-worlds-most-polluted-seas/ (Available 2016-06-02)

Bird, Eric. 2010. *Encyclopedia of the World's Coastal Landforms.* New York: Springer.

Conte, Marc, Kotchen, Matthew, 2010. Explaining the price of voluntary carbon offsets. *Climate Change Economics* 1: 93-111. Doi: 10.1142/S2010007810000091

Everett III, Hugh. 1963. Generalized Lagrange Multiplier Method for Solving Problems of Optimum Allocation of Resources. *Operations Research*. Vol. 11, No. 3: 399-417. Stable URL: http://www.jstor.org/stable/168028

Forex. 2016. *Aktuella kurser.* https://www.forex.se/Valuta/Aktuella-kurser/ (Available 2016-04-18)

Fuss, Sabine, Golub, Alexander and Szolgayová, Jana. 2014. Innovation and risk-averse firms: Options on carbon allowances as a hedging tool. *Energy Policy 70: 227–235*. Doi: http://dx.doi.org/10.1016/j.enpol.2014.03.012

Gren, Ing-Marie, Lindahl, Odd and Lindqvist, Martin. 2009. Values of mussel farming for combating eutrophication: An application to the Baltic Sea. *Ecological Engineering 35: 935–945*. Doi: 10.1016/j.ecoleng.2008.12.033

Gren, Ing-Marie, Lindqvist, Martin. 2014. Cost-effective management of a eutrophied sea in the presence of uncertain technological development and climate change. Working Paper 2014:01, Department of Economics, SLU, Uppsala.

Gren, Ing-Marie, Lindqvist, Martin and Jonzon, Ylva. 2008. *Calculation of costs for nutrient reductions to the Baltic Sea – technical report.* Working paper 2008:1. Department of Economics, SLU, Uppsala.

Grönkvist, Stefan, Lind, Mårten, Olsson, Alexander and Yan, Jinyue. The elephant in the room – A comparative study of uncertainties in carbon offsets. 2015. *Environmental Science & Policy 56; 32–38.* Doi: http://dx.doi.org/10.1016/j.envsci.2015.11.004

Hart, Rob, Hernroth, Bodil, Kollberg, Sven, Lindahl, Odd, Loo, Lars-Ove, Olrog, Lars, Rehnstam-Holm, Ann-Sofi, Svensson, Jonny, Svensson, Susanne and Syversen, Ulf. 2005. Improving Marine Water Quality by Mussel Farming: A Profitable Solution for Swedish Society. *AMBIO: A Journal of the Human Environment, 34(2):131-138*. Doi: http://www.bioone.org/doi/full/10.1579/0044-7447-34.2.131

Havet. u.d.a *Övergödning.* http://www.havet.nu/?d=31 (Available 2016-06-01)

Havet. u.d.b *Fakta om egentliga Östersjön. http://www.havet.nu/?d=43* (Available 2016-05-21)

Helcom. 2016a. *Baltic Sea Action Plan.* http://helcom.fi/baltic-sea-action-plan/action-plan/ (downloaded 2016-02-22)

Helcom. 2016b. *PublicationBSEP115b.* http://www.helcom.fi/Lists/Publications/BSEP115b.pdf (downloaded 2016-02-25)

HELCOM. 2013. *Helcom Copenhagen Ministerial Declaration*. http://helcom.fi/helcom-at-work/ministerial-declarations (downloaded 2016-04-18)

Lantbruk och musselodling i samverkan - en miljöåtgärd i tiden

Lindahl, Odd. u.d. *Musselodling en lönsam miljöåtgärd.*

Lindqvist, Martin. 2008. *Värdet av musselodlingar som reningsåtgärd i en kostnadseffektiv rening av kväve och fosfor från Östersjön.* Swedish University of Agricultural Science. ISSN 1401-4084

Neumann, Thomas, Schernewski, Gerald and Stybel, Nardine. 2012. Zebra Mussel Farming in the Szczecin (Oder) Lagoon: Water-Quality Objectives and Cost-Effectiveness. *Ecology and Society 17(2): 4.* Doi: http://dx.doi.org/10.5751/ES-04644-170204

Rosenberg, Rutger and Loo, Lars-Ove. 1983. *Energy flow in a Mytilus edulis culture in western Sweden*. Aquaculture 35, 151 – 161.

SVT, 2008. *Lysekil- Musselodling polisanmäls. http://www.svt.se/nyheter/lokalt/vast/lysekil-musselodling-polisanmals (Available 2016-06-13)*

The Economic Times. u.d. *Definition of "Risk Averse".* *http://economictimes.indiatimes.com/definition/risk-averse* (Available 2016-05-12)

Woodward, R. T. 2011. Double-Dipping in Environmental Markets. Journal of Environmental Economics and Management 61(2): 153-169.

WorldbyMap. 2015. *Coastline Length*. http://world.bymap.org/Coastlines.html (Available 2016-06-03)

Figures

Map Figure 3.

Elofsson, Katarina. 2010. Cost-effectiveness of the Baltic Sea Action Plan. *Marine Policy 34 (2010) 1043–1050.* Doi: 10.1016/j.marpol.2010.03.003