Cost-effectiveness analysis in reducing nutrient loading in Baltic and Black Seas: A review

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Abstract

Eutrophication represents a global environmental pressure that necessitates international co-operation and the diffusion of information to avoid information asymmetries, the construction of an appropriate legislative framework, the development of monitoring technologies and scientific research to provide the evidence base for any policy interventions. The health condition of the Baltic and Black Seas has deteriorated over a long period due to increases in nutrient inputs from anthropogenic and non-anthropogenic sources. The current report aims at providing a review of the literature and defining the possible gaps concerning (1) the attempts at regulatory intervention to address the problem of eutrophication in the Baltic and Black Seas, (2) the methodological issues in constructing a cost-effectiveness analysis, (3) the available applications of cost-effectiveness studies conducted and (4) the uncertainties and risks entailed in the cost-effectiveness studies.

Keywords: Eutrophication; cost-effectiveness analysis; abatement measures; nutrient loading; Baltic Sea; Black Sea.

JEL Classifications: Q00; Q01; Q25; Q50; Q53.

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<http://cordis.europa.eu/fp7/home_en.html>

1. Introduction

Nutrient loading corresponds to the amount of nitrogen (N) or phosphorus (P) coming into the water in a specific time period from groundwater or from the air as wet (rain, or snow) or dry depositions. Although some level of nutrient loading can be beneficial to the health of natural ecosystems (for primary production), excess amounts adversely affect ecosystem state and potentially can affect public health (van Buuren et al., 2002). Nutrient enrichment contributes to oxygen depletion and increases the population blooms of toxic algae (Wulff et al., 2001). Camargo and Alonso (2006) and Smith (2003) summarise the ecological and toxicological effects of eutrophication in aquatic systems which include the deterioration of water transparency and light availability, the sedimentation of organic matter and oxygen depletion in bottom waters. Nutrient loading also affects productivity and species composition.

Anthropogenic sources of nutrient loading mainly derive from various agricultural, industrial and urban activities. Pollution can be categorized as point and non-point source pollution. The latter can include runoff into water bodies from a range of agricultural land and construction sites, as well as atmospheric deposition. The outflow of nutrients from a catchment depends on specific water discharge, soil type, land use, catchment slope, population density, *etc* (Meybeck, 1993). The major nitrogen input contributor has been estimated to be the agricultural sector diffusing about 80% of the total load (HELCOM 2004, 2009).

In order to reduce nutrient loading, criteria have been enforced that define water quality standards. One of the top priorities of the US Environmental Protection Agency (EPA) is the protection of water bodies from pollution arising from nutrient loading. As a result it has been suggested that US States adopt numeric nutrient standards relying on three basic features (USEPA, 2012):

(i) the uses of water bodies for activities such as fishing, recreation, *etc*;

(ii) the specific level of pollutants that cumulatively do not affect the assimilative capacity of the water bodies (i.e. a threshold constraint); and

(iii) the defined measures and policies that provide protection and sustainable management of the quality of waters.

The structure of the current report is the following. First, the methodological issues to construct a cost-effectiveness analysis are addressed. Next, a review of the existing relevant literature concerning the regulatory intervention to address the problem of eutrophication in the Baltic and Black Seas is presented. Moreover, the available cost-effectiveness studies conducted are summarized and finally the potential uncertainties and risks entailed in the cost-effectiveness studies are discussed.

2. Methodological issues in applying cost-effectiveness analysis

A cost-effectiveness analysis (CEA) is used to assess the relative performance of potential measures with respect to achieving alternative objectives. Explicitly, it helps the decision maker in an appraisal to find the best alternative activity, process or intervention that has the lowest predicted resource use to accomplish a desired result or target. Cost-effectiveness analysis represents one of the key economic tools to be included in an integrated plan of policy making to manage resources efficiently. The challenge vis-à-vis nutrient loading is to reduce emissions in a cost-effective way.

Cost-effectiveness analysis can be applied both as ex-ante and ex-post evaluation tools. As an ex-ante tool, it focuses on the investigation of the most cost-effective solution for a given resource reduction target. Policy makers try to introduce and implement a concrete and consistent policy to achieve the desirable emission reduction. After determining an objective quantified in physical terms, a CEA finds the least cost measure (or series of measures) for achieving the resource reduction targets. If applied as an ex-post valuation tool, policy makers can address the question of how far objectives have been achieved and at what cost.

In general terms the fundamental building blocks required to apply the CEA methodology include a comprehensive review of the potential impacts of the abatement options (expressed in non-monetary units), a prediction of the likely effectiveness of measures and an assessment of the costs of alternative options that are measured in monetary terms (Balana et al., 2011).

Mitigation of harmful emissions is a target of legislative frameworks worldwide such as the European Union, the United Kingdom Climate Change Act and the Kyoto Protocol with the view of reducing greenhouse gas emissions by 5% below 1990 levels during the period of 2008-2012. The Inter-governmental Panel on Climate Change was established in 1988 by the World Metereological Organisation (WMO) and assessed technical and socioeconomic research in the field of climate change. Another policy framework is the United Nations Framework Convention on Climate Change (UNFCCC) which entered into force in 1994 and established commitments vis-à-vis the stabilization of greenhouse gas concentrations in the atmosphere. The application of CEA should go hand-in-hand with the development of new policy options and frameworks.

2.1 Applications

Different approaches are used to conduct a cost-effectiveness analysis. Most of these approaches rely on basic types of mathematical programming like linear programming (LP), non-linear programming (NLP) and integer programming (IP) model formulations. Optimization is one of the common features that mathematical programming models involve. The basic elements of the mathematical programming model include the decision variables, the constraint function(s), the bounds such as non-negativity and the objective function. It is important to build the objective function that includes the quantity that we wish to maximize or minimize (Williams, 2013). Specifically CEA can be based either on minimization of costs given a determined environmental target or on maximization of benefits given a specific budget frame (Balana et al., 2011).

Although linear programming (LP) models require reliability and precision of the data to be properly applicable, they are still used in various fields (Rommelfanger, 1996). Azzaino et al. (2002) applied a binary optimization model in order to allocate effectively the budget outlay. Cuttle et al. (2007) applied linear programming models to estimate the cost-effectiveness of measures to decrease diffuse water pollution from agriculture in the UK. Balana et al. (2012) integrating biophysical and economic data applied the optimization model used by Azzaino et al. (2002) to identify optimal buffer widths to achieve cost effective water quality targets. Fezzi et al. (2008) build upon past work (Cuttle et al., 2007) and try to estimate the cost effective policies to reduce nutrient loading. Bartolini et al. (2007) used a multi-attribute linear programming model to evaluate the impacts of agriculture and water policy changes on the economic, social and environmental sustainability of certain irrigated farming systems in Italy. Fröschl et al. (2008) using a linear optimization model evaluated selected measures in agricultural production to reduce nitrogen loads in the water bodies of Austria, Bulgaria, Hungary and Romania.

Concerning integer programming (IP) models, Messer (2006) used a binary linear programming where the integers are limited to zero or one in order to estimate the maximum conservation benefits for a land acquisition effort. Börjesson & Ahlgren (2012) applied a bottom-up partial equilibrium optimization model based on MARKAL. The techno-economic features of the study are represented by a mixed-integer linear programming (MILP) model. The study focuses on investigating the least cost utilization levels to tackle with the increased use of biogas. Moreover, in Europe several tools for sustainable management of water resources have been applied. The Environmental Costing Model (EnCM) is designed to find the most cost-effective measures under the Water Framework Directive (WFD) by means of mixed integer programming. Surface water target pollutants include chemical oxygen, nitrogen and phosphorus (Wustenberghs et al., 2008).

Another frequently used tool is the Soil and Water Assessement Tool (SWAT) which has gained international acceptance as a robust watershed modelling and is linked to a hydrological assessment (Cools et al., 2011). Specifically Cools et al. (2011) in the framework of a hydro-economic modelling which consists of a modular coupling between the hydrological water quality model SWAT and the economic optimization model EnCM tried to set up a cost-effective program of measures to achieve a target. Ullrich & Volk (2009) used SWAT to investigate the effects of management practices to reduce nonpoint source and water pollution resulting from agricultural activities. Panagopoulos et al. (2011) investigated the most cost-effective solutions to reduce sediments such as nitrates, nitrogen and phosphorus to surface waters using SWAT model. Lescot et al. (2013) proposed a methodological framework for spatially-distributed cost-effectiveness analysis to compare various agro-environmental measures to control pesticide pollution in surface waters. Various other studies use SWAT for impact assessment (Chaplot et al., 2004; Arabi et al., 2006; Bracmort et al., 2006; Gassman et al., 2006; Santhi et al., 2006; Tong and Naramngam 2007; Nendel, 2009; Pandey et al., 2009; Sahu and Gu 2009; Volk et al., 2009; Douglas-Mankin et al., 2010; Glavan et al., 2011; Rabotyagov et al., 2010; Rossi et al., 2012; Kaini et al., 2012; Baker & Miller, 2013).

According to Heinz et al. (2007) hydro-economic optimization tools can identify combinations of diverse actions, such as availability of water resources and legislative rules. Optimization models though, can identify which is the best action and then is further assessed through simulation studies. Simulation models are applied to estimate the impacts of specific alternative policies. Thus, simulation and optimization models are useful tools for the selection of the right combination of an integrated management plan in the context of socioeconomic and legal objectives. The increased necessity for the assessment of the economic impacts of a policy and especially of a water management policy has driven the development of mathematical models that combine hydrological and economic properties (Brouwer and Hofkes, 2008). Hydro-economic models represent spatially distributed water resource systems, infrastructure, management options and economic values in an integrated manner (Harou et al., 2009), while various studies include hydro-economic modeling (Gómez-Limón and Riesgo, 2004; Pulido-Velázquez et al., 2008; Volk et al., 2008; Brouwer et al. 2008; Maneta et al., 2009; Varela-Ortega et al., 2011; Blanco-Gutiérrez et al., 2013).

The stochastic nature of many factors such as temperature, climate, soil, nitrogen cycle and generally the complexity of interactions between economic, agronomic and hydrologic systemς, suggest that management policies cannot be accurate and well predicted. However, if we do not take into consideration the uncertainty in a model, this could lead to unreliable results. McSweeny and Shortle (1990) applied cost-effectiveness analysis to include uncertainty by the alternative policies. Bystrom et al. (2000) tried to take into account uncertainty of controlling nitrate pollution in wetlands. Lacroix et al. (2005) used a bio-physical model to evaluate the probabilistic cost-effectiveness of farm management practices to reduce nitrate pollution. Berbel et al. (2011) proposed a methodological approach including uncertainty for cost-effective measures in the context of the EU Water Framework Directive (WFD). Other studies incorporating uncertainty in the structure of the model is the ones of Elofsson (2003) and Gren et al. (2000, 2002).

According to Shen et al. (2008) the uncertainty of the models consists of structural uncertainty, input data uncertainty and parameter uncertainty. Structural uncertainty is investigated through the comparison of the performance of different models. Input data uncertainty is handled using random variables as input data to include changes like natural conditions and limitations of measurement. Finally, parameter uncertainty is dealt with the application of various methods such as sensitivity analysis, first-order error analysis (FOEA), maximum likelihood, Bayesian analysis, regional sensitivity analysis, the genetic algorithm, the Fourier amplitude sensitivity test and various other methods like Monte Carlo (MC), bootstrap, discrete Bayes, neural network and fuzzy mathematical technique (Qin et al., 2007; Savic & Walters, 1997; Wen & Lee, 1998; Barton et al., 2008; Brouwer & De Blois, 2008; Wu et al., 2006).

As concerns the non-linear nature of cost-effectiveness analysis there are numerous studies that have been applied in the field of environmental economics. Bio-economic modelling combines biophysical and economic processes. Semaan et al. (2007) used an approach that combines a biophysical model and a mathematical programming model in order to develop a bio-economic model to analyze the effects of agricultural policies on farmer's profits and nitrate leaching system. Mouratiadou et al. (2010), by selecting cost-effective measures to regulate agricultural water pollution to conform to the Water Framework Directive, applied a bio-economic modelling approach to explore the water quality and economic effects of the 2003 Common Agricultural Policy Reform.

Schou et al. (2000) integrated economic and environmental modelling to analyze policies in terms of their cost-effectiveness for Danish agriculture. Brady (2003) has evaluated the relative cost-efficiency of agricultural policy using a spatially distributed nonlinear programming model. Yang et al. (2003) under the framework of a program to reduce sediment loading in the Illinois River investigated the cost effective alternatives using a non-linear programming model. Schuler and Sattler (2010) showed how a bio-economic model can be applied to estimate the cost-effective solutions on agriculture and the risk of soil erosion.

The selection of an appropriate model requires the availability of data and an interdisciplinary effort, in terms of the cooperation of natural scientists, economists and stakeholders to contribute in establishing the environmental and socio-economic criteria of the optimisation (Bouraoui & Grizzetti, 2013).

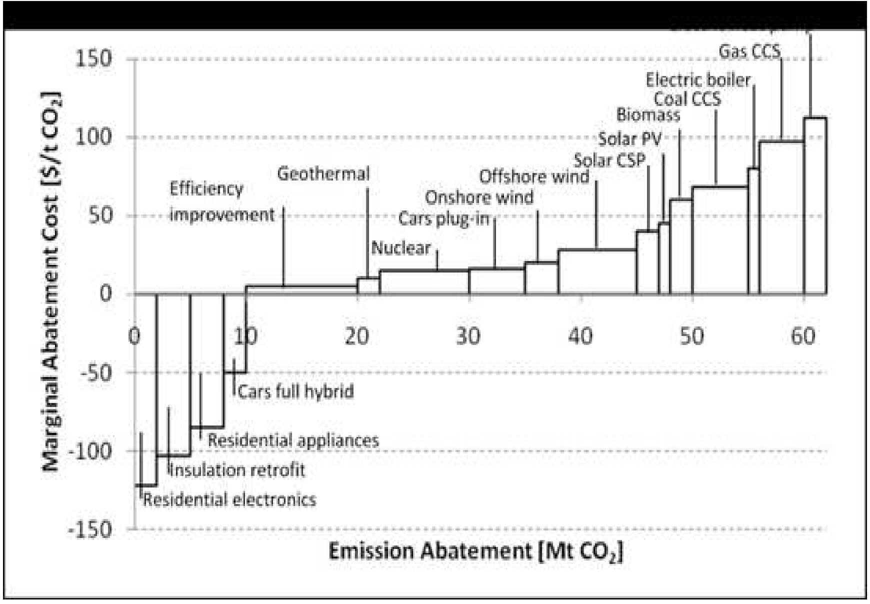
2.2 Marginal Abatement Cost Curves

Marginal Abatement Cost (MAC) curves represent a standard policy tool to assess the economics of complex environmental issues (Kesicki and Strachan, 2011). MAC curves have been developed to illustrate the costs associated with emissions abatement like in the case of sulphur or carbon dioxide emissions and to determine the optimal level of pollution control. The construction of abatement cost curves increases the environmental awareness of firms in terms of giving insight into the most cost efficient measures to abate emissions (Beaumont and Tinch, 2004; McKintrick, 1999).

MAC curves adopt various shapes as a result of variations in inter- and intra-sectoral options for mitigation and also on the time horizon which is selected (Kesicki, 2010). There are various methods to construct an abatement cost curve. Initially a simplified method is to construct a supply abatement curve or else a “savings curve”. According to Jackson (1991), Naucler and Enkvist (2009) and Kesicki (2010) a supply curve combines the supply side options for meeting the pollutants’ reduction target. The most cost-effective options appear at the far left of the MAC curve and vice versa as it can be seen in Figure 1. Each step of this stepwise curve represents one option being applied in isolation (for details see Halkos 1993, 1995, 1996a, b, 2010).

The height of each bar represents the cost in $ per unit of pollutant abated (e.g. 1 tonne CO_2-equivalent) and the width refers to the magnitude of the possible abatement for each mitigation option assessed for a specific year. The cost curve may not only include positive costs but also negative costs. The abatement options with negative costs are defined in the literature as ‘no regrets’ mitigation options (Metz, 2007).

Figure 1: Cost-effective options in a MACC curve



Source: Kesicki and Strachan (2011)

The existence of negative costs means that society would benefit from the specified mitigation actions even if there was no benefit from the abatement *per se* (in terms of reductions in morbidity/mortality, *etc*). In a *cost-benefit analysis* the value to society of the benefit of (in this case) reducing emissions by one Mt CO_2 would be put side by side with the marginal abatement costs. If the estimates of these social benefits were (say) \$100/t CO_2 then all measures that had a marginal abatement cost of \$100/t CO_2 would satisfy the cost-benefit criterion of efficiency, i.e. broadly speaking it would be optimal in economic terms to adopt such measures. The same principle can be carried forward to the economic analysis of nutrient loading reductions.

A cost-effectiveness analysis can be conducted when appropriate data on abatement costs at resource reductions and their impacts on the targets are available.

Ideally, data is available on total costs of alternative reductions levels where total cost includes the net abatement cost at the source and the distribution of impacts on the economy. A more thorough analysis can be carried out when there are several abatement options and different locations with different social, economic and environmental characteristics.

3. Regulation to reduce nutrient loading

Eutrophication is one of the key pressures on the health of estuarine, coastal and marine ecosystems all over the world. According to OSPAR (2008, p. 107) and to European Community (1991) legislation, marine eutrophication is defined as ‘‘the enrichment of water by nutrients causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned, and therefore refers to the undesirable effects resulting from anthropogenic enrichment by nutrients”.

There is a host of regulations that pertain to reduce nutrient loading. For the purposes of the current review, the focus is on the Baltic Sea (section 3.1) and the Black Sea (section 3.2). These sections do not focus on the specific regulations per se but rather on the *governance structure* or legislative framework that supports the application of legislative interventions in these two specific regional seas.

3.1 Baltic Sea legislative framework

One of the major environmental problems of the Baltic Sea is eutrophication. Over time, anthropogenic pressures have contributed to species and habitats degradation. Morphological characteristics are also conducive to eutrophication. The slow rate of water passage through the narrow Danish Straits and Sound areas linking the Baltic to the North Sea is a key reason for the sensitivity of the Baltic Sea to eutrophication because of the slow renewal of oxygen in deeper basins (Bendtsen et al., 2009).

Moreover, we have vertical stratification that averts oxygenation of the bottom waters and sediments of the water masses which is a consequence of the large inflow of freshwater from the catchment area surrounding the Baltic, including many rivers. As a result, significant quantities of phosphorus are accumulating in the aquatic area (HELCOM, 2009). Between 1955-1990 the annual atmospheric deposition of dissolved inorganic nitrogen doubled and now represents about a quarter of the total N input to the Baltic Sea which has contributed to an increase of water nutrients input (Danielsson et al., 2008). There is a well-developed agricultural sector and other human activities including fossil fuel combustion from energy production and transport that contribute to significant nutrient loading (HELCOM, 2009).

As it is depicted in Figure 2, the Bothnian Bay and the Swedish parts of the north-eastern Kattegat do not face the problem of eutrophication; the open waters of all other basins are classified as ‘affected by eutrophication’. This is related to the increase in chlorophyll-concentrations[1]. Neva, the largest river in the Baltic Sea, significantly affects the Gulf of Finland; the Gulf of Riga is strongly affected by the river Daugava and the city of Riga.

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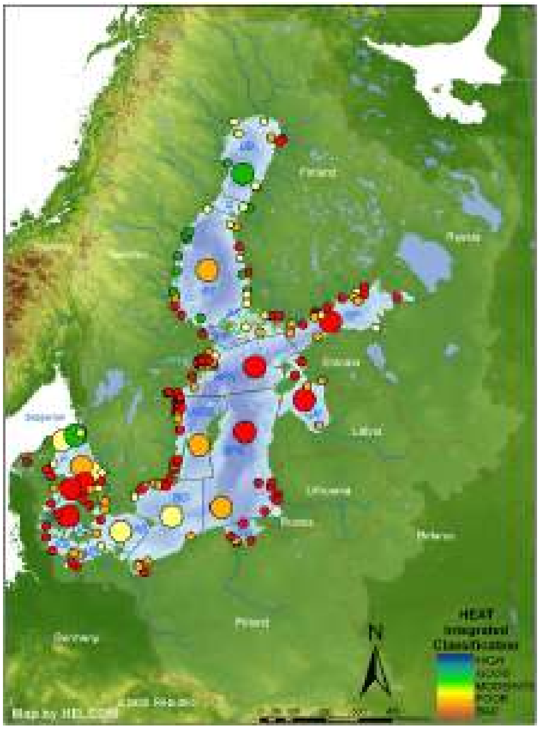
[1] Chlorophyll is found in a number of organisms and is bounded within the living cells of algae and phytoplankton in the surface water. Chlorophyll-a gives plants their green colour and it is a specific type of chlorophyll used in oxygenic photosynthesis. For a technical note on the basics of chlorophyll measurement see http://www.ysi.com/media/pdfs/T606-The-Basics-of-Chlorophyll-Measurement.pdf

Figure 2: Classification of eutrophication status



Source: HELCOM (2009)

In 1974, Denmark, Sweden, Finland, Soviet Union, Poland, and East and West Germany – countries that surround the Baltic Sea - formed the Helsinki Commission (HELCOM) and agreed to sign the Convention, which finally came into force in 1980, concerning the protection of the marine environment of Baltic Sea (Voss et al., 2011). Co-operation is the main target of HELCOM along with the full support of scientific research. Projects are aimed at the definition of pollutants criteria, development of monitoring mechanisms to ensure that HELCOM environmental standards are fully applied and abatement measures are fully developed by all Member States surrounding the Baltic Sea (Ebbesson, 1996). The Partners are obliged to apply the measures taking into account Best Environment Practice (BEP) and Best Available Technology (BAT) to reduce pollution from human activities. In 1992 a new Convention was signed by all the states bordering the Baltic Sea. The recommendations of the Convention include those affecting both inland and marine waters. The Helsinki Convention came into force in January 2000 and the latest amendments came into force in November 2008.

HELCOM achieved noticeable improvements in abating pollution and protecting the marine environment - for instance a 40% reduction in nitrogen and phosphorus discharges in total since the late 1980s (HELCOM, 2008). There still remain many environmental problems to be solved. Regarding inputs of nutrients which are responsible for eutrophication, one of the main objectives of the HELCOM Baltic Sea Action Plan is to reduce phosphorous discharges by around 42% and nitrogen discharges by around 18% by 2021. The Baltic Sea Action Plan was adopted in 2007 and its priority is to re-establish the good ecological status of the Baltic marine environment by 2021 and to combat the continuing deterioration of the marine environment resulting from human activities (HELCOM, 2008).

The Baltic Sea Action Plan's main challenges include the continuing eutrophication of the Baltic Sea, inputs of dangerous substances that affect biodiversity, the increase of algal blooms, dead sea-beds, and the depletion of fish stocks. The plan is based on Ecological Objectives to reflect a vision of a healthy marine environment, with various biological components functioning in balance, resulting in a good ecological status and supporting a wide range of sustainable human activities. Such objectives relate to the preservation of clear water, an elimination of the excessive algal blooms, and ensuring viable populations of species. Under the timeframe that the Baltic Sea Action

Plan establishes, targets for ‘good ecological statuses are being set and the exact actions needed in order to attain the targets (HELCOM, 2013).

Politicians at various forums and regions have already supported the HELCOM Baltic Sea Action Plan as it is a contribution to the successful implementation of the proposed plans in the region. Specifically, the EU Marine Strategy Directive expects the realization of such a plan by each and every Member State, so the HELCOM innovative action plan serves as a model example to be adopted by the Regional Seas Conventions and Action Plans, given the support of the United Nations Environment Programme. However, the European Union lately has turned into the most central institutional framework for addressing several cross-border policy issues including the eutrophication in the Baltic Sea region (Kern and Löffelsend 2008).

The transnational character of eutrophication in the Baltic Sea has led to the adoption of a European strategy for the Baltic Sea Region (EUSBSR) in 2009. The top priority is to address the problem and act in cooperation with all Member States. Specifically EUSBSR aims at organizing new projects and initiatives, creating a sense of common responsibility (European Commission, 2010).

The number of flagship projects that have been launched in the Baltic Sea region exceed 100. One of the projects that investigate the situation in the Baltic Sea in terms of nutrient loads is the CLEANSHIP which aims at anchoring the Clean Shipping Strategy in EU policies. The Fifth Pollution Load Compilation (PLC-5) acts under the provisions of BSAP and its overall objective is to measure and describe the nutrient loads from point and non-point sources of the Baltic catchment (HELCOM, 2011).

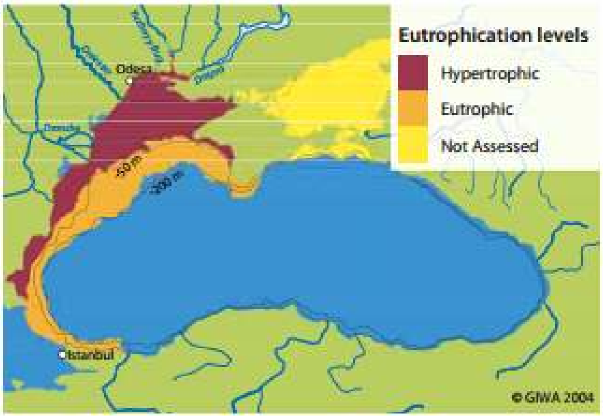
The PURE project aims at the enhancement of phosphorus removal at selected municipal wastewater treatment plants in the Baltic Sea region, assessing cost effectiveness while PRESTO is a flagship project based on the finding of the PURE project, focusing on improving the waste water treatment of plants in Belarus. Aquaculture is another domain that poses a threat to water quality in terms of increasing nutrient loads. The AQUABEST project develops spatial planning guidelines to contribute to the creation of sustainable aquaculture.

There are also more projects related directly or indirectly with the eutrophication in the Baltic Sea such as the Assessment of Implication of Different Policy Scenarios on Nutrient Inputs (2005-2006) and the BALTHAZAR project (2009-2012) that promoted the protection of the Baltic Sea from hazardous waste and agricultural nutrient loadings. The HELCOM EUTRO developed assessment tools for the harmonization of eutrophication criteria and measures including the establishment of reference conditions for different parts of the Baltic Sea (HELCOM, 2011).

3.2 Black Sea Legislative Framework

Eutrophication has been a serious problem in the Black Sea over the past four decades (Borysova et al., 2005; BSC, 2008, 2009). The Black Sea can be characterized as one of the most contaminated seas in the world that is polluted by the six coastal states (the Russian Federation, Ukraine, Romania, Bulgaria, Georgia and Turkey) and the European rivers that flow into the Black Sea. One of the main sources of pollution is the Danube River with associated domestic and industrial wastes. Over-fishing is another pressure that contributes to the deterioration of the environmental ecosystems of the Black Sea. Figure 3 sets out eutrophication levels in the Black Sea.

Figure 3: Eutrophication levels in the Black Sea



Source: Borysova et al. (2005)

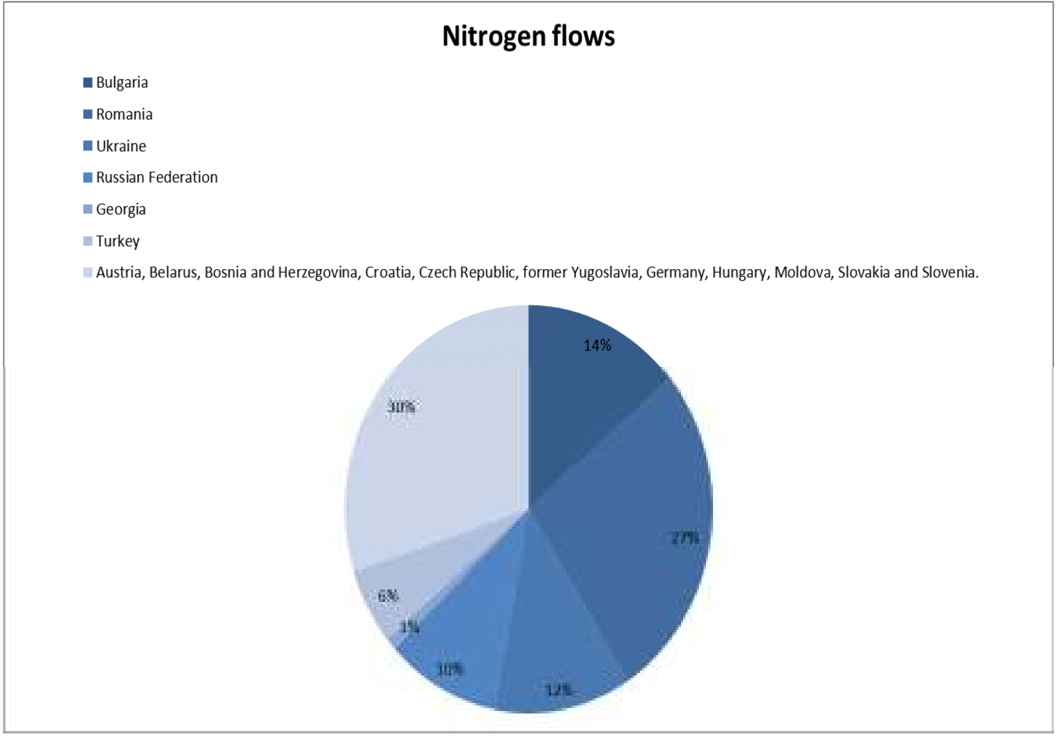
Enrichment of the water bodies by nitrogen and phosphorus discharges come from municipal, industrial and agricultural sources that represent the most significant sources of ecological degradation of the Black Sea (Glibert & Burkholder, 2006). The total nitrogen inputs in the 1990s are approximately more than six times higher than the nitrogen input to the Baltic Sea and more than twice the inputs to the North Sea (Artioli et al., 2008). Moreover, pollution of water bodies, and particularly the Danube, has caused significant damage to riparian regions through reduced profits from tourism and fisheries, loss of biodiversity and increased water-borne diseases.

According to Topping et al. (1998) 14% of total nitrogen derives from Bulgaria, 27% from Romania, 12% from Ukraine, 10% from the Russian Federation, less than 1% from Georgia, 6% from Turkey and about 30% from Austria, Belarus, Bosnia and Herzegovina, Croatia, Czech Republic, former Yugoslavia, Germany, Hungary, Moldova, Slovakia and Slovenia; this is set out in Figure 4. Concerning the phosphorous flows, 5% comes from Bulgaria, 23% from Romania, 20% from Ukraine, 13% from

Russia, 1% from Georgia, 12% from Turkey and 26% from the remaining countries; this is presented in Figure 5.

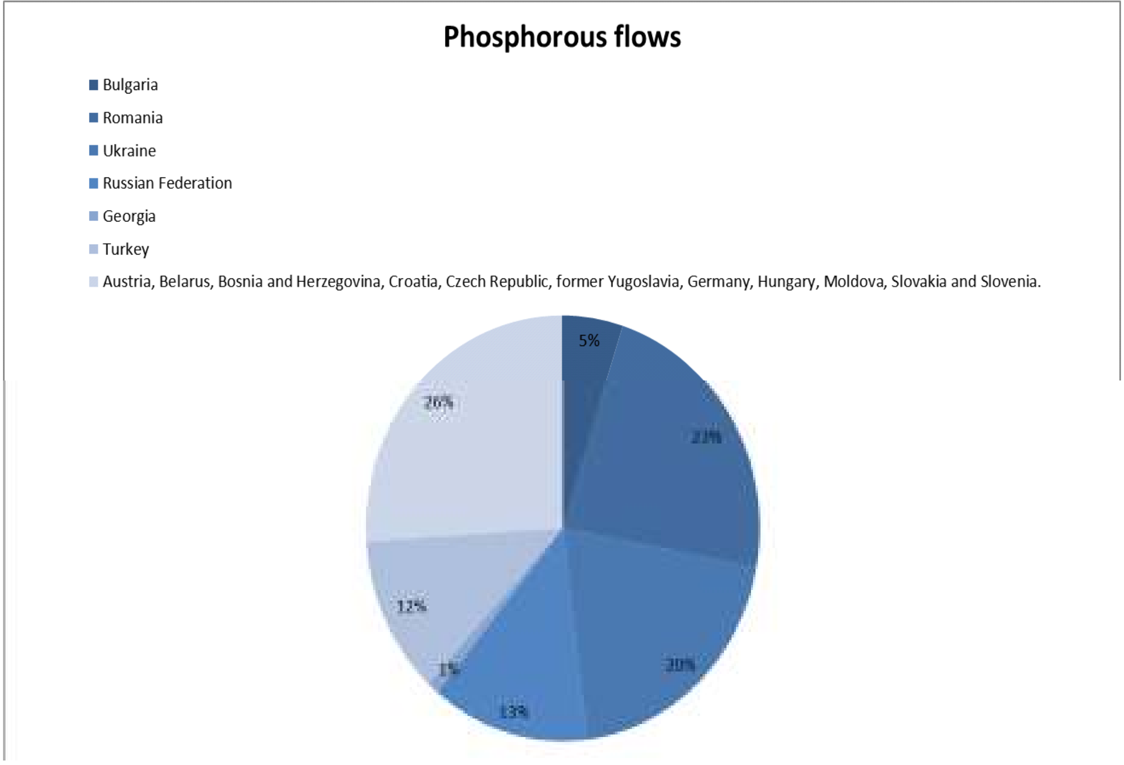
There have been some attempts at regional cooperation that have had a limited effect on the ground. These include Varna Fisheries Agreement signed in 1959 by Bulgaria, Romania and the former USSR; Bulgaria, Romania and Turkey cooperated in the General Fisheries Council for the Mediterranean Sea. Another attempt aiming at environmental protection was the MARPOL Convention of 1973 (Aydin, 2005). It was designed to reduce pollution of the seas and to preserve the marine environment and the minimization of accidental discharge of hazardous substances.

Figure 4: Proportion of nitrogen flows



Source: Authors' calculation following Topping et al. (1998)

Figure 5: Proportion of phosphorous flows



Source: Authors' calculation following Topping et al. (1998)

Problems in the Black Sea are due to the transboundary nature of pollution, which requires international cooperation. In the line of cooperation towards the preservation of marine ecosystem of the Black sea, was the Convention on the Protection of the Black Sea Against Pollution (Bucharest Convention) that was signed by Turkey, Romania, Ukraine, Bulgaria, Georgia and the Russian Federation in Bucharest in 21 April 1992 and entered into force in 15 January 1994. The Bucharest Convention entails 4 protocols: (i) the Protocol on Protection of the Black Sea Marine Environment Against Pollution from Land Based Sources, (ii) the Protocol on Cooperation in Combating Pollution of the Black Sea Marine Environment by Oil and Other Harmful Substances, (iii) the Protocol on the Protection of the Black Sea Marine Environment Against Pollution by Dumping and (iv) The Black Sea Biodiversity and Landscape Conservation Protocol. The main objective of the Contracting Parties is to prevent pollution by hazardous substances, land-based sources, wastes from vessels and emergency situations. Another objective is to prevent the pollution from the atmosphere and generally to provide framework for scientific and technical co-operation and monitoring activities (Borysova et. al., 2005; BSC 2009; EEA 2005; EEA 2006; Artioli et. al., 2008)

In 1996 the Strategic Action Plan for the Rehabilitation and Protection of the Black Sea was adopted. The target of the Strategic Action Plan is to achieve sustainable development in the Black Sea region. Specifically, it aims at enhancing the environmental health of the Black Sea and sustainable activities such as fishing, aquaculture and tourism in all the Black Sea countries. The Transboundary Diagnostic Analysis (TDA), which is a technical annex to this Strategic Action Plan, concludes that the Danube River is responsible for most of the nutrient input to the Black Sea.

In 2010, the European Union launched the Black Sea Environmental Partnership in order to develop sustainable regional measures needed to preserve biodiversity, marine and coastal ecosystems, to promote river basin management, to tackle pollution sources and promote environmental integration, monitoring, research and eco-innovation (EEA, 2010).

The Global Environment Facility (GEF) Strategic Partnership which unites 183 countries including countries surrounding the Black Sea and Danube Basin has been established with the cooperation of international institutions such as the World Bank (WB), the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP) and other multilateral and bilateral financiers and basin countries. The GEF funds various projects related to biodiversity, climate change, international waters, land degradation, the ozone layer and persistent organic pollutants to improve the global environment. Additionally, 'GEF River Danube Pollution Reduction Programme (GEF-RDPRP)' aims at developing new strategies for reducing pollution, including nutrients in the entire Danube Basin (Topping et al., 1998).

Another approach towards international cooperation concerning environmental issues is the International Commission for the Protection of the Danube River (ICPDR) that consists of 14 cooperating states and the European Union. It was established in 1998 to deal with the whole Danube River Basin, which includes its tributaries and ground water resources. Water quality is one of the issues that ICPDR addresses and as regards eutrophication is in charge of nutrient load allocation (ICPDR-ICPBS, 1999). Moreover, the TransNational Monitoring Network (TNMN) was developed to assess trends in water quality and to monitor physical, chemical and biological conditions in the Danube and its major tributaries.

An on-going project with the cooperation of HELCOM is the Baltic2Black (2011-2013) project related to environmental monitoring of the Black Sea with focus on nutrient pollution. The objective of the project is to improve the protection of the Black Sea from eutrophication via transmission of knowledge between the regions on assessment of eutrophication and monitoring of nutrient loads. The project's main tasks include the presentation of regionally agreed criteria for assessment of eutrophication, target concentrations and discussion on the development of eutrophication status classification in the Black Sea. Simultaneously, experts will share their experience on the use of automated monitoring systems for eutrophication and on the implementation of automated systems for monitoring eutrophication in the Black Sea region (DiMento & Hickman, 2012).

Lately, the 2012 Blueprint to Safeguard Europe's Water Resources under the European Commission was adopted. The sectors of main priorities for the preservation of water quality are agriculture and energy. This conclusion for Europe follows the findings of the 2009 River Basin Management Plan for the Danube, where hydropower generation, overexploitation of water bodies and diffuse pollution from the agricultural sector have been noted as being serious pressures. Moreover, the preservation of water quality has been addressed by the Scientific Support to the European Union Strategy for the Danube Region (European Commission, 2012).

4. Review of cost-effectiveness analysis studies

4.1 Baltic Sea

The Baltic Sea can be characterized as a public good. The state of the Baltic Sea plays a critical role in the economic assessment of the benefits derived from the sea including, among others, existence values, the value of services provided by marine ecosystems, as well as direct use values such as recreation and fishery (Markovska & Zylicz, 1999). There are only few studies investigating the economic values of eutrophication and mitigation in eutrophication levels in the Baltic Sea area (Elofsson, 2003; Söderquist, 1996; Markovska & Zylicz, 1999; Schou et al., 2006). The literature concerning the costs of reducing nutrients in the Baltic is very limited. The first Baltic-wide study was conducted by Gren et al. (1997a) and analyzed the minimum costs of reductions of nitrogen and phosphorus to the Baltic Sea. They considered 14 different regions and 15 different types of abatement measures for nitrogen and phosphorus emissions in the domain of agriculture, sewage treatment plants, energy and transportation.

Generally, the nutrient loads abatement measures include three types of measures:

(i) measures aimed at reducing the nutrient emissions transported by water streams,

(ii) Land use change and

(iii) Measures reducing the extent of nutrient contamination of coastal waters by increasing the nutrient retention on land.

Cost-effectiveness can be defined as achieving one or several environmental targets at minimum costs. A basic hypothesis for estimating cost-effectiveness is that the marginal costs of all possible measures are equal. If the hypothesis of equality of marginal costs is not satisfied the level of nutrient reduction is obtained at a lower cost. Specifically, the low costs measures are reduced while there is an increase by the same amount from measures with relatively high costs (Gren et al., 1997a, 1997b). The environmental target is defined as a reduction of the total load of nitrogen and phosphorus to coastal waters and the costs that are assessed for different reduction levels are fully compared. The empirical results show that if a least-cost strategy is adopted, a nitrogen reduction by 360 kton per year would cost approximately €2511 million per year. Similarly if a least-cost strategy is adopted, a phosphorus reduction of 18.5 kton would cost €626 million. Additionally, the empirical results show that abatement measures in wetlands, increased wastewater treatment and reductions in agricultural loads account for one third of the nitrogen load reduction when nitrogen loads are reduced by

50% in a cost-effective way. Simultaneously, measures for phosphorus at wastewater treatment plants account for two thirds of the reductions (Gren et al., 1997).

Gren (2008) analyses and compares the costs of two strategies against transboundary water pollution mitigation and adaptation measures using a chance constrained programming. The comparison of the two international policies such as cooperation and national uniform standards shows that mitigation under non-cooperative uniform national standards can be increased when considering stochastic pollution and linkage in risk between mitigation and adaptation measures.

HELCOM and NEFCO (2007) report addresses the costs and effects of abatement measures against eutrophication in the Baltic Sea and the impact of these measures for policy scenarios recommended by the BSAP. The study includes all countries adjacent to the sea and measures for nitrogen and phosphorus reduction are related to waste water treatment, livestock reductions, improved manure management, conversion of agricultural land into grassland, catch crops, reduced fertilizer use and NOx reductions for stationary combustion sources, heavy vehicles and ships. Calculations demonstrate that the scenario that would reduce nitrogen loads by 106 kton and phosphorus loads by 13 ktons costs nearly €3.42 billion per year. The study sheds light into the most cost-effective measures that are reductions of NOx-emissions from shipping, catch crops, fertilizer reductions and a ban on phosphate detergents.

Elofsson (2003) develops a cost-effective model to rank agricultural measures such as the use of chemical fertilizers. The overall objective is to achieve the nutrient reduction target of 50% of total loads. Additionally the model takes into account the stochasticity of nutrient loads. This important extension of a standard model contributes to the achievement of abatement measure which is significantly more cost-effective than it would be without the stochasticity.

Updating the data used in the study of Elofsson (2003), Schou et al. (2006) develop a similar cost-effectiveness model for 24 regions adjacent to the Baltic Sea. The measures incorporated in the revised model include wetland restoration measures, reduced fertilizer use, introduction of catch crops and livestock reduction in agriculture, sewage treatment measures, NO_X reduction and blank measures that are applied in the model to enable updates of the model by insertion of more measures. All measures are assumed to be independent concerning the environmental impact on the Baltic Sea. The total cost of reducing nitrogen pollution to the Baltic Sea by approximately 160 kton is estimated at €940.68 million.

Extending the time span for the evaluation to 2005, Elofsson (2012) in an effort to appraise national nitrogen and phosphorus measures of Sweden established a cost-effective analysis. Measures used in the analysis include actions in wastewater treatment such as increased cleaning at sewage treatment plants, private sewers, p-free detergents for NOx emissions and selective catalytic reduction on power plants, ships and trucks. Measures used in agricultural sector include reductions in cattle, pigs and poultry, fertilizer reduction, catch crops, energy forestry, grassland, creation of wetlands, changed spreading time of manure and buffer strips. The cost-effectiveness analysis is conducted using an empirical programming model including all countries adjacent to the Baltic Sea. The total cost of the current national policy is approximately €200 million and €500 million for the BSAP target. To achieve the Swedish national target efficiently, abatement measures in agriculture should be used to reduce both nitrogen and phosphorus emissions. Meeting the BSAP emission reduction targets for Sweden would require higher total costs compared to the current cost-effective national target. It is obvious that the BSAP target cannot be achieved with the current annual budget for nitrogen and phosphorus emission abatement measures in Sweden.

As far as the benefits of the abatement of the eutrophication, Ahtiainen et al. (2012) in a sample of 10564 respondents inquired the willingness to pay (WTP) for reducing eutrophication in the Baltic Sea. They found that the shares of respondents willing to pay for two eutrophication reduction programs were highest in Sweden and Finland and lowest in Russia. These percentages are presented in Table 1. Specifically, willingness to pay was calculated first over half of Baltic Sea Action Plan (BSAP) targets, then altogether and then either of the two programs with the number of respondents per country shown in the last column.

Table 1: Percentages of respondents' WTP

	Share WTP for ½ BSAP (%)	Share WTP for BSAP (%)	Share WTP for either of both programs (%)	N of respondents
Denmark	54	53.7	54.9	1061
Estonia	53.9	56.4	58	505
Finland	62.1	63	63.4	1645
Germany	54.7	56.2	56.5	1495
Latvia	49.1	49.8	50.1	701
Lithuania	54.1	55.1	55.1	617
Poland	54.3	55	55.6	2029
Sweden	74.1	74.6	75.4	1003
Russia	31.1	32.2	32.4	1508
Overall average	53.7	54.6	55.2	10564

Source: Ahtiainen et al. (2012, p. 15)

The total WTP for attaining the ½BSAP and BSAP scenarios equals to €3090 m and €4120 m respectively. It is worth mentioning that large differences between WTP in the countries considered is observed, with mean WTP per person in Sweden to be the highest and the one corresponding to Latvia to be the lowest. Comparing these findings with previous estimates of the benefits of reduced eutrophication in the Baltic Sea (e.g. SEPA 2008), the current findings show a lower total WTP is justified mainly from the use of primary valuation instead of benefit transfer.

Moreover, there are differences in the valuation scenarios. In Ahtiainen et al. (2012) the enhancement of the environmental status in the Baltic Sea differs from the sea basins and good status is not attained everywhere; whereas in the Baltic Drainage Basin Project (BDBP) the eutrophication level was expected to be reduced to a sustainable level (Söderqvist, 1996; Gren et al., 1997b; Turner et al., 1999; Markowska & Zylicz, 1999). At the same time, the time frame to achieve environmental changes differs from 40 years in Ahtiainen et al. (2012) to 20 years in the BDBP study.

Recently, Hyytiäinen et al. (2013) relying on these 10564 responses across the nine Baltic Sea countries (Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Sweden and Russia) monetized the benefits of eutrophication reduction by using CVM studies in these countries. The cost functions that have been applied were based on Ahlvik et al. (2013) study. In terms of cost-effective abatement measures the computation was performed with the assistance of non-linear optimization to attain the Baltic Sea Action Plan (BSAP) targets. The study includes the ecological objectives and the impacts of the agreement. The results indicate that the benefits of reducing eutrophication exceed the costs, explaining why the protection of the Baltic Sea and the objectives set in the

BSAP should be continued. Table 2 presents the costs and benefits of attaining BSAP nutrient load reduction targets for each riparian EU country as well as Russia and in terms of country-wise and basin-wise constraints for nutrient loads as well as the setting as constraint of the Good Environment Status (GES) of the Baltic Sea.

Taking into account that the abatement measures are planned cost-effectively Table 2 depicts that the net benefits in million € (in 2012 constant prices) per annum are equal to 894, 1377.1 and 2249.5 in terms of country-wise, basin-wise and the Good Environment Status (GES) of the Baltic Sea constraints respectively. According to Hyytiäinen et al. (2008) important factors influencing the profitability of investment in control measures are the costs of the best nutrient abatement actions, the effectiveness of nutrient control of seawater quality as well as the proportion of the population benefitting from the improved environment in terms of ecosystem and recreational activities.

Table 2: Costs and benefits of attaining BSAP nutrient load reduction

	Country-wise target			Basin-wise target		GES of Baltic Sea	
	Benefits m€/yr	Costs m€/yr	Net Benefits m€/yr	Costs m€/yr	Net Benefits m€/yr	Costs m€/yr	Net Benefits m€/yr
Denmark	202.91	638.6	-435.7	649	-445.9	275	-72.1
Estonia	17.5	37.1	-19.6	80.3	-62.8	37.1	-19.6
Finland	188.5	50.47	138	23.7	164.8	53.6	134.9
Germany	1865.33	670.5	1194.8	494.4	1370.9	101.9	1763.4
Latvia	6.18	126.7	-120.5	87.5	-81.4	56.65	-50.5
Lithuania	25.75	138	-112.3	104	-78.3	85.5	-59.7
Poland	200.85	755.6	-574.7	560.3	-359.5	597.4	-396.5
Sweden	780.74	335.8	445	298.7	482	217.3	563.4
Russia	495.43	116.4	379	108.15	387.3	109.2	386.25
EU countries	3287.76	2772.8	515	2297	989.8	1424.5	1863.3
All countries	3783.2	2889.2	894	2406.1	1377.1	1533.7	2249.5

Source: Modified from Hyytiäinen et al. (2013, p. 13)

Ahlvik et al. (2013) and Hasler et al. (2012) investigated the costs of a reduced eutrophication in the Baltic Sea under the BSAP targets using different data sources. The results are still comparable and reveal that if all measures included in Ahlvik et al. (2013) were implemented to their full capacity, the annual amount of load reduction in the Baltic Sea would be 248,377 tons of nitrogen and 16,731 tons of phosphorus. Similarly, if all measures in Hasler et al. (2012) were implemented to their full capacity the annual load reduction to the Baltic Sea would be 214,292 tons of nitrogen and 12,500 tons of phosphorus. That variation can, partially, be explained by the application of the measures adopted in wetland, fertilizer and livestock reduction.

Studies investigating cost-effectiveness of agricultural nutrient reductions in the Baltic basin include Ollikainen and Honkatukia (2001), Gren (2001) and Eloffson (1997) who compare cost-effective policies with the target of 50% reduction in nitrogen and phosphorus to the Baltic Sea. The aforementioned studies include all countries adjacent to the sea. The results show that a nitrogen reduction by 429 kton would amount to €152,550 million provided that reductions are comparable to all countries. Similarly phosphorus reduction by 35 kton would cost almost €12.15 billion. However, cost effective measures correspond to €20,520 million for nitrogen and €1,215 million for phosphorus.

In Finland one of the most studied areas is the catchment in the lake Pyhäjärvi. Iho (2004) analysed a cost-effective reduction of the phosphorus load derived from the river Yläne. The reduction target is set to 10% and the alternative methods to reduce phosphorus pollution include buffer strips, constructed wetlands and reduced use of fertilizer.

Iho (2005) develops a model to investigate the cost-effective allocation of three measures to reduce phosphorus load. In the Southwestern Finland, Helin et al. (2008) studied abatement costs for agricultural nitrogen and phosphorus loads from agriculture. Nutrient reduction costs are evaluated under the Common Agricultural Policy reform (CAP) in the Uusimaa and Varsinais-Suomi provinces in Southern Finland. Results show that a 50% reduction in agricultural nitrogen load would cost €27.4 to €30.7 million or €2188.5 to €2410 per farm. Hyytiäinen et al. (2008) introduce a stochastic simulation model that integrates nutrient dynamics of nitrogen and phosphorus in arable land of Finland. The results indicate that investments in reducing the nutrient load from arable land in Finland would become profitable only if the neighbouring countries in the northern Baltic committed themselves to similar reductions.

Although case studies concerning economic analysis in Germany are sparse, Mewes (2012) conducted a cost-effective analysis to assess the most effective solution in the agricultural sector to reduce nutrient loads by 25% or even by about 50% using the MONERIS model in the time framework of 1998-2000. Data as regards nutrient emission and land use were combined from a total of 19 river catchments. The abatement measures included in the CEA case study include advisory service about the use of organic and inorganic fertilizer, restoration of wetlands and converting arable land into either less intensely used arable land, grassland, set-aside land or afforestation with or without use, extensively used buffer strips coupled with a ban to use fertilizer and grassland buffer strips. The total cost of achieving the 25% nitrogen nutrient reduction target amounts to €9-34 million yearly. Furthermore, the 50% reduction cannot be achieved without new additional measures for either nutrient. In the case study a simultaneous reduction of nitrogen and phosphorus was considered. The results show that advisory service should be taken into account as a low cost measure. That cost-effectiveness solution is of great importance for policymakers with the objective to reach agreed reduction targets at minimal costs.

4.2 Black Sea

Borysova et al. (2005) provide the first economic assessment of the damage caused by eutrophication in the catchment of Ukraine. The study tried to investigate the costs of legislation compliance due to nutrient enrichment. The results show that the total value of the economic damage resulting from eutrophication, for the 5 studied regions in Ukraine is €14.88 million per year and there is a need to tackle the problem on a national, regional and/or international level.

Fröschl et al. (2008) carried out a cost-effectiveness study to rank the alternative policies that reduce emissions derived mainly from the agricultural sector of the Danube River. Countries involved in the study were Austria, Bulgaria, Hungary and Romania. The four alternative measures to be implemented include the reduction in fertilizer use by 10%, the reduction of ammonia emissions from manure by 25%, increase plant productivity in Austria by 10% and in the other three countries by 20%, a reduction of erosion by 75% and surface run-off by 20%. The reference scenario was to accomplish the reduction targets by 2015. The measures are assessed empirically using a linear optimization model to find the best combination of measures that minimize the total costs of nitrogen pollution.

The effectiveness was calculated by using the Model of Nutrient Emissions in River Systems (Behrendt et al., 2002). In the case of no international cooperation, the maximum nitrogen emission reduction of the four countries amounts to 18,000 tonnes per annum and costs €1,107.97 million yearly. The cost-effective solution in Austria and Hungary is the increasement in plant productivity by applying capital intensive production techniques, in Austria by 10% and in the other three countries by 20%. These techniques include irrigation systems that are tailored to different zone's climate and soil consistency, plant protection against various insects and weeds and improvements in plant nutrition. The most cost-effective measure for Bulgaria and Romania is the reduction of ammonia emissions from manure by 25%. In the case of effective international cooperation the total cost of the reduction target of 14,809.5 tonnes per year was negative and equal to -98.73 million € (Behrendt et al., 2002).

One of the tasks of UNDP-GEF Black Sea Ecosystem Recovery Project is to investigate cost-effective measures to minimize nutrient pollution. Dworak et al. (2008) established the methodological framework of the task aiming at introducing policy makers in the Black Sea countries to basic cost-effectiveness assessment approaches along with identifying the vital data required to carry out the assessment of measures for monitoring and controlling sources of nutrient pollution. The approach includes three sectors that provide the major contribution of nutrient pollution in the Black Sea - agricultural, municipal and industrial. Bonham (2006) conducted an indirect study related to the nutrient pollution in the Black Sea. Specifically, Bonham addresses cost-effective measures to reduce groundwater nitrate-N pollution from agriculture sector using an integrated biophysical simulation model and farm economic optimization.

Even though the problem of eutrophication in the Black Sea is profound and there is a sufficient legislative framework to secure the preservation of water bodies, cost-effectiveness studies and economic analysis case studies to abate nutrient pollution are very limited for the Black Sea and there is a need for further scientific research. Table 3 presents a summary of the cost-effectiveness studies discussed so far giving attention to the allocation of costs of abatement measures and nutrients reduction in Baltic and Black Seas.

Table 3 Summary of cost-effectiveness studies - Allocation of costs of abatement measures and nutrients reduction in Baltic and Black Seas

Baltic Sea

	Author(s), date	**Region-Country**	**Method**	**Pollutants**	**Measures**	**Total Cost of N reduction (in million €)**	**Total Cost of P reduction (in million €)**	**Total reduction (tones of N)**	**Total reduction (tones of P)**	**Reduction targets**
1	Gren et al. (1997a)	14 drainage basins surrounding the Baltic Sea	Linear cost functions	Nitrogen and Phosphorus loads	Sewage treatment plants	< 417.6	835.2	109 200	12 950	0-50% reduction of nitrogen and phosphorus
					Agricultural deposition of fertilizers and manure	< 417.6	< 208.8	109 200	1 850	
					Restoration of wetlands	< 417,6	208.8	109 200	3 700	
2	Turner et al., (1999)	Baltic drainage basin	Linear cost functions	Nitrogen and Phosphorus loads	Improvement in sewage treatment	346.8	346.8	158 527	12 833	50% reduction of nitrogen and phosphorus
					Reduction in agricultural deposition of nutrients	522.45	n.a	178 982	n.a	
					Restoration of wetlands	<346.8	174.5	143 186	6 611	
3	Gren (2008)	9 Countries surrounding the Baltic Sea	Chance constrained programming	Nitrogen loads	Coordinated solution where overall costs are minimised	462.5	n.a	190 400	n.a	0-40% reduction of nitrogen and phosphorus
					National solutions where countries disregards impacts on total covariance with unadjusted target	1 294		199 920		
4	HELCOM and NEFCO (2007)	Baltic Sea	Bottom up analysis	Nitrogen and Phosphorus loads	Improved wastewater treatment	2 737		35 000	12 900	40% of the total N loads and 30% of the P loads
					Reduction of 55% of the NOx emissions from shipping	36.8		10 000	n.a	14% of the total N loads

					Reduction of agricultural land	880.65		61 000	n.a	50% of the total N loads and 35% of the P loads
5	Elofsson (2003)	Baltic Sea	Non-linear programming model	Nitrogen and Phosphorus loads	Reduction in livestock holdings and changes in land use	<145.4	n.a	7 000- 8 000	n.a	50% reduction of nitrogen and phosphorous
					Reduction of fertilizers	436.4	<145.4	63 000-64 000	9 000	
					Changes in manure handlings	<145.4	n.a	30 000	n.a	
					Reduction in livestock holdings	n.a	<145.4	n.a	600-700 kg	
					Changes in land use	n.a	<145.4	n.a	2 000	
					Reductions in point source load of N/P	291.3	<145.4	60 000	5 800	
6	Schou et al., (2006)	Baltic Sea	Non-linear programming model	Nitrogen and Phosphorus loads	Wetland restoration	57.8	n.a	n.a	n.a	20% reduction of nitrogen
					Reduced fertiliser use	367.3	n.a	n.a	n.a	
					Introduction of catch crops in agriculture	246.9	n.a	n.a	n.a	
					Livestock reduction in agriculture	237.2	n.a	n.a	n.a	
					Improved treatment of sewage	11.1	n.a	n.a	n.a	
					NOX reduction	0.468	n.a	n.a	n.a	
7	Elofsson (2012)	Sweden	Empirical programming model	Nitrogen and Phosphorus loads	**Current national targets**					20% reduction of phosphorus, 30% reduction of nitrogen
					Wastewater sector	2.4	20.4	107	198	
					NOx emissions	100.8	n.a	3 611	n.a	
					Agricultural sector	62.4	7.2	13 173	152	
					Baltic Sea Action Plan catchment targets					20% reduction of phosphorus, 30% reduction of nitrogen
					Wastewater sector	39.6	86.4	557	246	

					NOx emissions	91.2	n.a	3 204	n.a	
					Agricultural sector	7.2	4.8	16 074	89	
8	Iho (2005)	River Yläne basin	Numerical model	Phosphorus loss from fields	Reduced use of fertilizer, buffer strips and constructed wetlands	n.a	0.169	n.a	0.745	10% reduction of phosphorous
9	Helin et al., (2008)	Finland	Integrated agri-environmental model	Agricultural nitrogen loads	Reduced fertilizer use and buffer strips	25-28	n.a	n.a	n.a	50% reduction of nitrogen
10	Mewes (2012)	Germany	semi-empirical, conceptual model (Modelling Nutrient Emissions in River Systems model-MONERIS model)	Nitrogen and Phosphorus loads	Advisory service	7.5	7.5	1 606	38.2	25% reduction nitrogen and phosphorus
					Conversion of arable land on sandy soil	22.6	22.6	1 645	44.9	
					Re-establishment of wetlands on marshy soil	8.2	8.2	204	18	
					Buffer strips	0.932	1.7	15	1.1	
11	Ahlvik et al. (2013)	Baltic Sea	non-linear optimization model	Nitrogen and Phosphorus loads	Reduced fertilization	n.a	n.a	118 684	1 672	Objective 1: Country and sea-basin-specific targets Objective 2: Sea-basin specific target Objective 3: Nutrient loads leading to the BSAP good ecological status
					Catch Crops			17 429	99	
					Reduction in cattle numbers			32 986	472	
					Reduction in number of poultry			6 402	108	
					Reduction in number of pigs			13 938	369	
					Restoring wetlands			75 521	907	
					Constructing phosphorus ponds			n.a	1 773	

					Improving wastewater treatment				42 926	9 772	
					Banning Phosphorus in detergents				n.a	3 324	
12	Hasler et al. (2012).	Baltic Sea	non-linear optimization model	Nitrogen and Phosphorus loads	Reductions in fertilizer applications to arable crops	n.a	n.a		72 875	n.a	Objective 2: Sea-basin specific target
					Catch crops under spring-sown cereals				38 440	n.a	
					Reduction in cattle numbers				35 765	1 031	
					Reduction in number of pigs (poultry and pigs)				6489	373	
					Restoring wetlands on agricultural soils				78 803	959	
					Improving wastewater treatment				50 245	16 693	
13	Hyytiäinen et al., (2013)	9 Countries surrounding the Baltic Sea	non-linear optimization model	Nitrogen and Phosphorus loads	Reduced inorganic fertilizers	**Obj. 1:**	**Obj. 2:**	**Obj. 3**	n.a	n.a	Objective 1: 37% reduction of P and 19% reduction of N Objective 2: 36% reduction of P and 19% reduction of N Objective3: 38% reduction of P and 16,6% reduction of N
						927	721	206			
					Reduced animal holding	515	412	<72.1	n.a	n.a	
					Improved wastewater treatment	721	721	721	n.a	n.a	
					Wetlands	515	309	309	n.a	n.a	
					Catch crops	103	72.1	<72.1	n.a	n.a	
					Reduced detergents	154.5	<72.1	103	n.a	n.a	
					Sedirnentation ponds	72.1	72.1	103	n.a	n.a	

Black Sea										
	Study	**Region, Country**	**Method**	**Pollutants**	**Measures**	**Total Cost of N reduction (in million €)**	**Total Cost of P reduction (in million €)**	**Total reduction (tones of N)**	**Total reduction (tones of P)**	**Reduction targets**
14	Frosch et al., (2008)	Austria, Bulgaria, Hungary and Romania	semi-empirical, conceptual model (Modelling Nutrient Emissions in River Systems model-MONERIS model)	Nitrogen loads	Reduction of fertilizer use by 10%	55.9	n.a	19 857	n.a	10% reduction of fertilizer use, 25% reduction of nitrogen emissions from manure, 75% reduction of erosion and 20% reduction of surface runoff
					Reduction of ammonia emissions from manure by 25%	1 127	n.a	2 762	n.a	
					Reduction of direct nitrogen emissions into the hydrosphere	128.3	n.a	8 130	n.a	
					Increase of plant productivity by application of capital-intensive production techniques	132.8	n.a	5 443	n.a	

5. Uncertainty and Risks

Cost-effectiveness analysis is related directly to the abatement measures as it investigates the most cost-effective way to combine them. The abatement measures though, can be characterized by some kind of uncertainty regarding their effects and costs. Those uncertainties can be grouped into three different categories such as natural, economic and technological uncertainties.

Natural uncertainty is caused by temporal and spatial variations of the biochemical and physical processes. As a result, the creation of a reliable model will depend on natural variations such as precipitation and temperature and therefore it will lead to variations in total costs of the presumed reductions targets. Some studies have tried to incorporate stochastic pollutant transports in their cost-effectiveness models to account for uncertainty (Gren et al. 2000, 2002). Similarly, Gren (2008) examined the impact of risk linkages between mitigation measures on cost-effectiveness solutions to given pollution reductions under conditions of stochastic loads to water recipients. Elofsson (2003) took into account stochastic relationships between abatement measures and nutrient loads and tried to examine the relations using chance constrained programming models.

Climate change is another element of uncertainty, impinging on issues such as flooding, water scarcity and droughts which pose a serious threat to water quality. Water management is directly affected by climate variations as it is difficult to set efficient and viable targets and as a result to conduct a cost effectiveness analysis. According to Wilby et al. (2006) incorporating climate variability at critical stages of the management framework such as the Water Framework Directive could lead to disproportionate costs and failure to reach assigned targets. Bio-physical models that can include climatic variables are appropriate for examining the cost effectiveness of management practices. Lacroix et al. (2005) proposed the use of bio-physical models in assessing the cost-effectiveness of the farm management practices, allowing for climate variability. Concerning the Baltic Sea, Lindkvist et al. (2013) calculate cost-effective solutions to reductions of nutrient loads under different scenarios with respect to impacts of climate change on nutrient loads.

Economic uncertainty is related to the real cost of alternative management practices. Asymmetric information can partially explain a part of the abatement cost uncertainty in the sense that those who implement the measures (e.g. farmers) usually have more information concerning the abatement costs. Berbel et al. (2011) conduct a sensitivity analysis to consider uncertainty in both costs and effects estimates using a simulation tool. As the non-linear nature of effectiveness and costs of measures were recognized in a number of CEA studies, nonlinear bio-economic optimization models have been developed by integrating the bio-physical process and the economic behavioural models (Balana et al., 2011).

If there are several unknown variables that have significant impact on the analysis more elaborate approaches must be considered. Brouwer and Blois (2008) used a statistical analysis based on Monte Carlo simulation to estimate the impact of environmental and economic uncertainty on the selection of cost-effective policy measures. Moreover, a recently developed literature relates to the usefulness of Bayesian Belief Networks in water management decision making (Barton et al., 2006; 2008). Barton et al. (2008) adopting a Bayesian network methodology for South Eastern Norway evaluated results and uncertainties of the nutrient pollution and the cost-effectiveness analysis.

Another source of uncertainty is the discount rate used for the optimization. Discount rates affect investment costs of abatement measures if costs and benefits are included as annual values.

Finally, *technological uncertainty* relates to the actual abatement capacity of a specific technology. Technological progress would minimize the cost of alternative technologies over time. This obviously would make it more cost-effective to abate environmental pollution including the increased nutrient inputs in marine environments. However, technological change is not simply an autonomous process that takes place regardless of policies chosen but it is the result of a complex web of factors involving prevailing and expected prices, consumer values, taxes and regulations, and technology policies. According to Lindqvist and Gren (2013) an important source of technological change is learning-by-doing. The results of the study show that the impact of learning-by-doing on the costs of abatement can be significant depending on the learning rate. As a result technological change could lead to substantial cost decreases of pollution.

6. Summary - Main points

Excessive concentrations of nutrients such as phosphorus and nitrogen lead to the environmental pressure of eutrophication worldwide. In order to reduce nutrient loading, there is a large evolution of international legislative frameworks and organizations – both governmental and non-governmental - to address possible solutions. One of the top priorities of the US Environmental Protection Agency (EPA) is the protection of water bodies from the effects of nutrient-sourced pollution.

One of the major environmental problems of the Baltic and Black Seas is eutrophication. Over time both Seas have been affected by a variety of human activities that result in species and habitats degradation arising from enrichment with nutrients. In the Baltic Sea anthropogenic pressures are exacerbated by the morphological characteristics of the region.

The efficiency of the actions to reduce nutrient loads requires careful investigation using a cost-effectiveness analysis. The term cost-effectiveness can be referred to as a situation where the cost to effect ratio is minimized with specified restrictions. The definition of an efficient total cost curve requires three basic steps. The first step includes the specification of the objective that describes and reflects the problem. The second step requires the estimation of the effect of abatement measures with respect to the specific target. Lastly, the cost of abatement measures has to be assessed.

In the Baltic Sea there are few studies to address the least cost strategy reducing nitrogen and phosphorus loadings such as Gren et al. (1997), Gren (2008). Studies investigating cost-effectiveness of agricultural nutrient reductions in the Baltic basin include Ollikainen and Honkatukia (2001), Gren (2001), Eloffson (1997), Helin et al. (2008), Mewes (2012).

In the Black sea, although the problem of eutrophication is profound and there are plenty of measures to reduce nutrient inputs, cost-effectiveness studies are limited to those of Fröschl et al. (2008) that established a cost-effectiveness study in the agricultural sector of the Danube River and Bonham (2006) who addresses cost-effective measures to reduce groundwater nitrate-N pollution from agriculture sector. Overall outcomes were provided in Table 3.

The abatement measures of CEA though can be characterized by uncertainty regarding their effects and costs. These uncertainties can be grouped into different categories. Natural uncertainty is caused by temporal and spatial variations in biochemical and physical processes. Climate change is an important factor in uncertainty analysis and as a result water management is directly affected by climate variations as it is difficult to set efficient and viable targets. Economic uncertainty is related to the real cost of alternative management and technological uncertainty relates to the actual abatement capacity of a specific technology. Technological change is not simply an autonomous process that takes place regardless of policies chosen but is the result of a complex web of factors.

Although there are some attempts to describe the uncertainties, the literature is limited and there is a need to define the factors of uncertainty in order to construct efficient and reliable management measures and policies.

Finally, it is worth mentioning that areas may also differ in terms of socio-economic, environmental and urban-planning levels and these differences have to be taken into consideration in any environmental policy planning (Halkos and Salamouris, 2003).

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