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List of figures

List of tables

List of Abbreviations

AC	Abatement costs	**LVL**	Latvian lats
AIS	Automatic Identification System	**Marpol (73/78)**	International Convention for the Prevention of Pollution from Ships
As	Arsenic	**MeO-PBDEs**	Methoxylated polybrominated diphenyl ethers
BAU	Business as usual	**MSFD**	Marine Strategy Framework Directive
BIAS	Baltic Sea Information on the Accoustic Soundscape (project)	**N**	Nitrogen
BONUS	Baltic Organisations Network for Funding Science	**NECA**	NO_X Emission Control Area
BSAP	Baltic Sea Action Plan	**NEFCO**	Nordic Environment Finance Corporation
BSR	Baltic Sea Region	**Ni**	Nickel
C10H8	Naphthalene	**NH_4^+**	Ammonium
C16H10	Pyrene	**NO_X**	Nitrogen oxides
CAFE	Clean Air For Europe	**NO_2**	Nitrogen dioxide
CH4	Methane	**NO_3^-**	Nitrate
CHBr2Cl	Dibromochloromethane	**OH-PBDEs**	Hydroxylated PBDEs
CICES	Common International Classification of Eco-system Services	**P**	Phosphorous
Cd	Cadmium	**PAH**	Polycyclic aromatic hydrocarbon
CMAQ model	Community Modeling and Analysis System model	**Pb**	Lead
Co	Cobalt	**PM**	Particulate matter
CO2	Carbon Dioxide	**PO43-**	Phosphate
CO2eq	Carbon Dioxide equivalent	**PSU**	Practical Salinity Unit
Cr	Chromium	**PTS**	Permanent hearing threshold shift
Cu	Copper	**RoPax**	Roll-on/roll-off passenger (ship type)
CuPT	Copper pyrithione	**RoRo**	Roll-on/ roll-off (ship type)
dB	Decibel	**RV**	Reproductive volume
DCOIT	dichlorooctylisothiazolinone	**SECA**	Sulphur Emission Control Areas
DIN	Deutsches Institut für Normung	**SEK**	Swedish Krona
DPSIR	Driving forces, Pressures, States, Impacts and Responses (framework)	**SHEBA**	Sustainable Shipping and Environment of the Baltic Sea region
EEA	European Environment Agency	**Si**	Silica
EEDI	Energy Efficiency Design Index	**SMOKE model**	Sparse Matrix Operator Kernel Emissions Mod-eling System
EMEP	European Monitoring and Evaluation Pro-gramme	**SO2**	Sulphur dioxide
ERGOM	Ecological Regional Ocean Model	**SOx**	Sulfur oxides
ESS	Ecosystem Services	**SSP1**	Sustainability (cumulative scenario)
EUR	Euro	**SSP2**	Middle of the Road (cumulative scenario)
FMI	Finnish Metrological Institute	**SSP3**	Fragmentation (cumulative scenario)
GHG	Greenhouse gases	**STEAM model**	Ship Traffic Emission Assessment Model
GETM-ERGOM	General Estuarine Transport Model-Ecological Regional Ocean Model	**TAC**	Total abatement costs
HELCOM	Baltic Marine Environment Protection Com-mission	**VOC**	Volatile Organic Compounds
HC	Hydrocarbons	**VOLY**	Value of life years
Hg	Mercury	**VSL**	Value of statistical life
Hz	Hertz	**VTT**	Technical Research Centre of Finland
IAS	Invasive alien species'	**WP**	Work package
IPCC	Intergovernmental Panel on Climate Change	**WTP**	Willingness to pay
kHz	Kilo Hertz	**Zn**	Zinc
LNG	Liquified Natural Gas	**ZINEB**	Zineb
LPG	Liquefied Petroleum Gas	**ZnPT**	Zinc pyrithione

Report on ecosystem services linked to shipping in the Baltic

Shipping is vital to the global economy for trade and in particular for countries strong in trade like those surrounding the Baltic Sea. Transport of goods and comodities makes up the largest part of shipping activities compared to passenger shipping and cruise shipping. This report aims to provide an understanding of the costs of degradation to the environment as well as human health due to shipping in the Baltic Sea. The report provides an overview of the pressures created, changes to state of environment and health, and ultimately how this could impact human well being.

The assessment is based on the DPSIR (Driver-Pressure-State-Impact-Response) framework, which was adapted in the BONUS SHEBA project to the Baltic Sea and shipping. The framework was developed to assess the linkages from the pressures of shipping in the Baltic Sea to its effects on ecosystem services and human well being. Two main assessment approaches for costs of degradation are used: an analysis of ecosystem services and an estimation of abatement costs. Compared to other activities, shipping is as an important driver for the increase of non-indigenous species and physical impacts. NO_X and PM emissions and underwater noise are also important pressures from shipping compared to other land and sea-based drivers. These pressures lead to changes in the state of the environment and have the potential to lead to significant impacts on ecosystem services and human well being. Impacts are expected for tourism and recreation as well as recreational fishing, mainly due to eutrophication and oil spills. Genetic resources can be especially influenced by invasive species. Human health is influenced by a broad variety of drivers beyond shipping but is still highly influenced by shipping in local settings, e.g. especially where large harbours are close to or in big cities. A case study on air emissions shows costs of degradation on human health of 2.8 billion EUR for the year 2012 caused by enhanced ozone and PM concentrations for the whole Baltic Sea area. The case study on water emissions described the effects of NO_X emissions on the cod spawning areas with estimated costs to commercial fishing of around EUR 1.4 million for the year 2012. The case study on underwater noise showed that significant knowledge gaps still exist, and in particular about the causalities between underwater noise and human well being, making it not possible to provide monetary or quantitative results.

In addition, a costs based approach focusing on the costs (i.e. abatement costs) of technologies and measures to avoid or reduce environmental pressures leading to degradation was used. The evaluation of abatement costs estimates average total environmental cost of air and water pollution caused by shipping in the Baltic Sea with EUR 4.70 billion in 2014, EUR 2.84billion in 2030, and EUR 2.17billion in 2040. RoPax ships, container ships, chemical tankers, general cargo ships and bulk cargo ships are the main contributors of pollution in terms of abatement cost. The reduction of the costs is completely due to the improvements regarding air emissions. The average abatement costs linked to air emissions are predicted to be EUR 3.82 billion in 2014, EUR 1.83 billion in 2030, and EUR 1.07 billion in 2040. The abatement costs of air emissions are decreasing between 2014 and 2040 in the BAU almost by 72 %. In 2014, the abatement cost of only NOx emissions accounted for 66 % of total abatement costs. The share of abatement costs of water emissions (19 % in 2014) is by far lower than costst of air emissions (81 % in 2014) and estimated with EUR 878 million in 2014, EUR 1,014 million in 2030 and EUR 1,095 million in 2040. It is increasing by 25 % from 2014 to 2040. Copper contaminants from shipping makes up a large proportion of impacts on the ecosystem in terms of abatement costs. This metal's share is over 88 % of total abatement cost of water pollution from shipping. The costs are also analysed in different scenarios. The analysis of single scenarios of specific pressures shows that abatement costs are most reduced by an implementation of a NECA in 2021, a measure which has already been decided. It potentially reduces the abatement costs by 25 % in 2030 and almost 60 % in 2040 (compared to a future without NECA). The increased use of LNG especially by all new RoRo and RoPax ships and half of fuel used by other ship types is also reducing the abatement costs by about 13.7 % in 2030 and 14.2 in 2040 (compared to BAU). Various regulations limiting emissions to water from shipping, including prohibiting black water emissions, the discharge of grey water and or bilge water, no open loop scrubbers, having the Ballast Water Management Convention in place, and the use of only biocide-free paint, would reduce the abatement costs by 26 % in 2030 as well as 2040, compared to BAU.

The results of the assessment show that the environmental externalities and impacts on human well being by shipping could be reduced. At first based on the technological improvements and adjusted regulations which are already assumed in the BAU which would reduce the air emissions and their effects significantly. Different single scenarios also show a potential to reduce costs of degradation. Especially the *LNG scenarios* shows a major effect on costs linked to air emissions. Costs from water emissions could be reduced by a *Zero emissions to water scenario*, e.g. including adjustments of the MARPOL regulations. The potential of policy measures to reduce pressures from shipping will be further analysed in the BONUS SHEBA project.

A number of challenges and further research needs were identified during the assessment and should be mentioned and discussed. The design of the assessment framework, and the overall DPSIR framework, means that while linkages can be identified it was not possible to fully identify feedback loops within the system and account for their effects on human well being. Different data gaps limited the assessment, in many instances it was not possible to identify up-to-date or complete data sets linking to various elements of the assessment (i.e. pressures, state, and ecosystem services). Data was often not complete for the Baltic Sea area or was reported on a national level, meaning data for other marine areas was included, such as the North Sea. The number and quality of sources for shadows prices used in the abatement cost approach show a broad variety between the different emissions. For some emissions especially water emissions, a very limited database for shadow prices was used to calculate abatement costs, which increases uncertainties for the estimation. For the noise case study, due to the lack of information and scientific results on the link between noise levels and impacts on fish and mammals a full quantitative assessment of impacts on human well being in this case study was not possible.

1 Introduction

This report aims to provide an understanding of the costs of degradation due to shipping in the Baltic Sea. To do this, the report provides an in-depth look at the pressures created, changes to state and health, and ultimately how this does or could impact human well being. Shipping pressures in the Baltic Sea are numerous, ranging from emissions to air and water emissions to noise emissions and their impacts can potentially lead to effects such as on human health, losses to commercial fishing or decreased tourist arrivals. Costs of degradation within this study encompass both the natural environment as well as social impacts. In addition, costs are understood as both losses to ecosystem services as well as costs incurred in an effort to abate the negative externalities of shipping (i.e. environmental costs). The result is both a quantitative and qualitative assessment and should be a useful guide to researchers, NGOs, industry, and policy makers seeking to know more about how shipping in the Baltic Sea impacts human well being and therefore support with the identification and prioritisation of policy options and measures to reduce pressures.

The Baltic Sea region has witnessed significant socioeconomic changes over the last twenty years. The EU Baltic Sea region has a population of about 85 million people in Denmark, Finland, Estonia, Germany, Latvia, and Sweden (EUBSR, 2017). In 2008, the highest rates of population growth along the Baltic Sea coastline were mainly in the predominantly urban regions, such as the Finnish region of Uusimaa (12 %), the Swedish region of Stockholms län (16 %), and the Latvian region of Pieriga (13 %) (Eurostat, 2011). The maritime economy of the Baltic Sea includes freight and passenger transport as well as fishing, tourism, shipbuilding, renewable energy and oil and gas drilling. Shipping is vital to the global market for trade and in particular for countries strong in trade like the countries surrounding the Baltic Sea. Transport shipping makes up the largest part of shipping activities compared to passenger shipping and cruise shipping. The region is also a major trade route for the export of Russian petroleum, and it is estimated that about 2,000 ships are at sea at any one time, while 150 - 200 large oil tankers are harboured in 20 ports around the sea each day. Shipping activities on the Baltic Sea, both in number and size of ships, have been rising over the last decade and are expected to increase further (HELCOM, 2010a). The fishing industry in the Baltic Sea has traditionally been centred on cod. During the peak of the industry in the 1980s it supplied the world with about 22 % of global cod catches. However, cod levels have severely declined throughout the 1990s and 2000s (Baltic Sea 2020, 2011).

The three year research project BONUS SHEBA aims to assess the environmental pressures from shipping in the Baltic Sea region and how this ultimately impacts human well being. The assessments of the environmental pressures from shipping are focused on emissions to air (Work Package 2), emissions/discharges to water (Work Package 3) and finally underwater noise (Work Package 4). Along with additional information and data, the results of these work packages are then used for an integrated assessment of shipping pressures on ecosystem services and human health (Work Package 5). Another key focus of BONUS SHEBA is to assess available policy instruments to reduce costs of environmental degradation and impacts on human health. Current policy and socioeconomic drivers affecting shipping and other vessels in the Baltic Sea region were analysed in the Deliverable 1.1 'Drivers for the shipping sector' (Boteler et al. 2015). This report provides a 'baseline' of key policy and socioeconomic drivers against which potential future changes (e.g. new policy instruments) affecting vessel activity can be assessed. It is therefore a reference point for scenario development and helps with identifying the most important drivers of changes to the shipping sector.

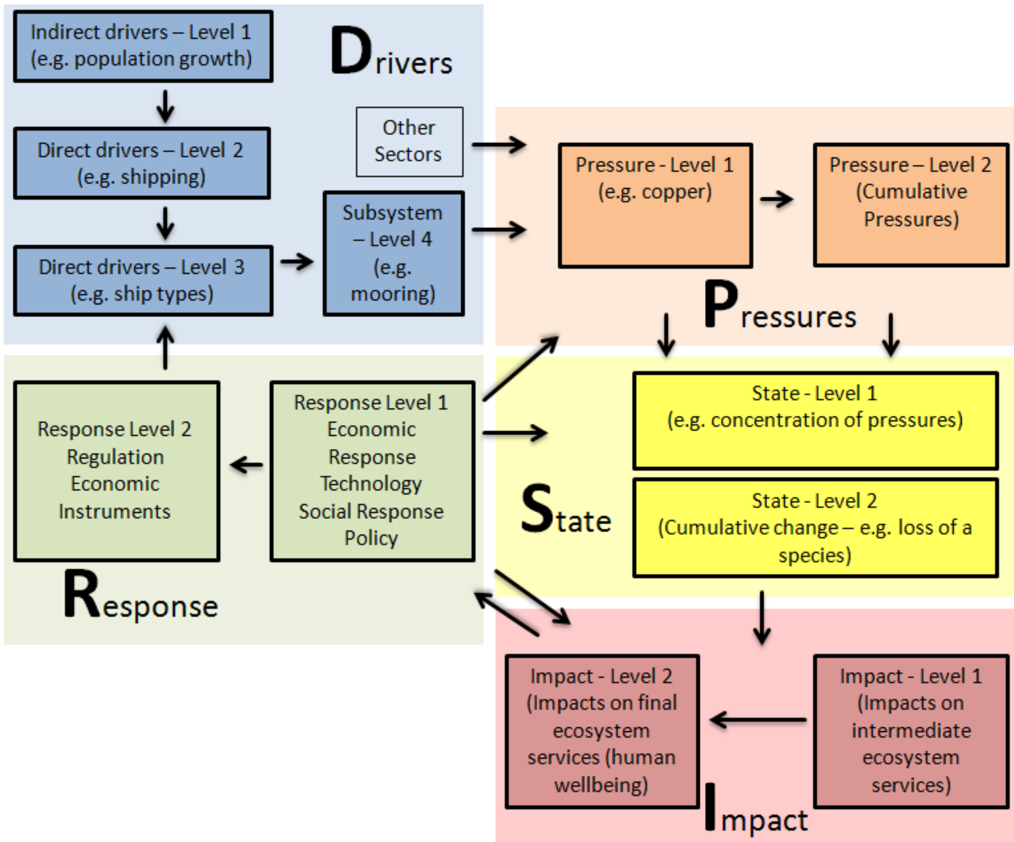
The objective of this report D5.2 'Report on ecosystem services compared to Business As Usual' is to assess changes to ecosystem services compared to the *BAU scenario* developed. The assessment is based on the DPSIR (Driver-Pressure-State-Impact-Response) framework, which was adapted in SHEBA D5.1 to the Baltic Sea and shipping. The focus of this assessment is on general cargo ships, bulk cargo ships, RoRo ships, RoPax ships, vehicle carriers, refrigerated cargo ships, cruise ships, oil tankers, product tankers, chemical tankers, LNG tankers and LPG tankers. SHEBA Deliverable 1.1 explained the drivers relevant within this framework. D5.2 describes the pressures, state and impacts of the adapted DPSIR. The upcoming SHEBA deliverable D5.3 will then cover responses and policy instruments.

This report provides an introduction, in section 1.1., of the analytical framework used to understand the links between pressures, state of the environment and human health, and impacts on human well being. This is followed by a brief overview of the scenarios developed to understand potential future changes to the shipping sector, and ultimately how this may affect human well being, in section 1.2. In Chapter 2, the overall approach and selected methodologies are explained. The bulk of the assessment on the costs of degradation are provided in Chapter 3, which assesses ecosystem services and also uses three case studies to focus in section 3.2 on specific pressures stemming from shipping. In a next section in the Chapter (section 3.3), the results of the cost based approach, focusing on abatement costs are provided. In Chapter 4 a summary of the combined costs is used to bring these two approaches together and better understand the overall costs to degradation as well as provide a brief overview about challenges and uncertainties faced when working on this report. Readers looking for a shortened version of this report are encouraged to skip to Chapter 4 directly.

1.1 Developing an assessment framework

Within BONUS SHEBA an assessment framework was created in Deliverable 5.1 'Report on analytical framework for assessment of shipping and harbours in the Baltic Sea' to understand and ultimately assess the linkages from the drivers of shipping in the Baltic Sea to its effects on ecosystem services and human well being. Available Drivers Pressures State Impact Response (DPSIR) frameworks were analysed and adapted to shipping in the Baltic Sea. The framework was adjusted to assess the impacts and changes from shipping on ecosystem services under different conditions. Drivers of change are understood as anthropogenic activities that may have an effect on the environment. These include indirect drivers, direct drivers, and their subsystems as shown in the figure below (Figure 1). Pressures describe how the driver and subsystems link to the environment. The pressures are characterised as a certain emission, discharge or load in the environment such as level of copper in the water. The state represents the condition of the ecosystem. It refers to concentrations or intensity of pressures in the environment (e.g. the concentration of a certain substance such as copper) (State Level 1). The accumulation of several individual substances could then lead to further changes such as loss of species of algae, birds or fish (State Level 2). The change of state of the environment is then leading to impacts understood as effects on ecosystem services. Impact Level 1 summarizes effects on intermediate ecosystem services e.g. supporting ecosystem services such as maintaining nursery population and habitats. Impact Level 1 is connected to Impact Level 2 which is impacts on final ecosystem services which affect human well being (i.e. beneficiaries) such as changes in recreational potential, food production and genetic resources. Within the BONUS SHEBA analytical framework, responses refer to all possible actions or reactions by society, economic actors and governments to address and cope with drivers, pressures, changes in state and impacts. Responses incorporate all possible strategies, such as societal adaption to new conditions, economic responses, as well as policies and instruments to reduce or mitigate pressures. However, the focus is on policy measures designed to improve the environmental performance of shipping.

Figure 1: The DPSIR framework for shipping in the Baltic Sea region



Source: adapted from Hassellöv et al, 2016.

1.2 Developing scenarios to understand potential changes

The different conditions for shipping are described via scenarios in Deliverable D1.4 'Future scenarios' (Fridell et al., 2016). During a workshop in Hamburg in September 2015 and using a World Cafe approach, stakeholders discussed technical developments which could influence the environmental impacts of shipping in the future.[1] These could be the use of different fuel types, possible abatement technologies for emissions to air and water, different engine types and their use. Socioeconomic developments were discussed as well, especially which economic developments (e.g. growing/shrinking sectors) will have an influence on transport demand and therefore shipping volume during the next years and decades. The information was included in the development of the BONUS SHEBA scenarios for e.g. shipping volume and emissions. Furthermore, an elicitation exercise was held in a workshop in Tallinn in October 2016. Experts estimated different future developments in the exercise.

A Business As Usual (BAU) scenario, seven 'single' scenarios and three 'cumulative' scenarios were developed for the years 2014, 2030 and 2040. The *BAU scenario* is mainly following current trends. It follows the general assumptions of the EU's transport policies and priorities e.g. opportunities for marine and maritime sustainable

[1] See Brief of Stakeholder Meeting: Considerations for the Baltic Sea Shipping Sector http://www.sheba-project.eu/imperia/md/content/sheba/deliverables/sheba_d1.2_final.pdf

growth (EC, 2012) and Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system (EC, 2011). Further, legislation and other regulations already decided upon are assumed to be enforced (SECA-limit, NO_X up to Tier III, decided EEDI limits) in the scenarios while other probable policy measures are not (see Table 1 below). Individual policy measures are included in the single scenarios. The report describes different scenarios which will lead to lower air emissions and partially also lower noise and water emissions: *slow steaming*, *NECA 2021*, increased use of *LNG* in new RoRo and RoPax ships. There is a special *zero emissions to water scenario* in which emissions of nutrients and invasive species will decrease. In a modal shift from *land to sea-scenario* the impact by shipping is increased through more RoRo and container traffic. One further scenario is focusing on leisure boats and stricter regulation on hull paint and air emissions. A port measures scenario focuses on lower emissions to air and noise as auxiliary engines not used while at berth.

Table 1: Included potential regulations in BAU

Topic	Included in BAU	Technologies	Comment
SOx emissions	SECA limit (0.1%) from 2015, global limit (0.5 %) from 2020	Assumed 10 % of ships are using LNG in 2040, use of scrubbers for all ship types in 2030 is 15 % and in 2040 20 % (based on fuel heat content), equally divided open and closed scrubbers*	The change of the global limit have no direct impact on BAU but may influence technology choices
NOx emissions	Tier III from 2021 for new ships	For Tier III basically use of selective catalytical reduction (SCR), exhaust gas recirculation (EGR) or LNG fuel	
Emission of greenhouse gases	The decided EEDI limits plus further actions	Described as EEDI and further technical improvements and more efficient operation	
Use of LNG	LNG 10 % of ships in 2040*	Dual fuel mainly	
Sewage water	Regulation for passenges ships (cruise ships and RoPax)	For passenger ships: 50 % of ships deliver to ports, 50 % have treatment plants which are 80 % effective	
Hull paint	Following current trends		

Source: Fridell et al, 2016

Note: *Based on SHEBA elicitiation exercise with experts

In order to illustrate the shipping volumes in the Baltic Sea following more general developments, cumulative scenarios were constructed. These follow the so-called Shared Socioeconomic Pathways (SSPs) described by O'Neill et al. (2014). Three of the SSPs were chosen for further development within BONUS SHEBA. These were chosen since they are expected to give a strong variation in the output for shipping in the Baltic Sea when it comes to volumes and implementation of environmental technologies. *SSP1* is named 'Sustainability' scenario and thus includes a sustainable development with high concern for the environment and good technology development with focus on renewables and efficiency. *SSP2* is the 'Middle of the Road' scenario where recent trends continue. This means a reduction in resource and energy use and slowly decreasing use of fossil fuel. For shipping, this scenario is here interpreted as the same as the BAU scenario. *SSP3* is the 'Fragmentation' scenario where there is development in some world regions and poverty in others leading to continued fossil fuel dependency and failure to meet environmental goals.

2 Approach

This report uses a threefold approach to assess the costs of degradation due to shipping in the Baltic Sea, focusing on environmental pressures as identified through impacts to ecosystem services as well human health. First, a stakeholder consultation was conducted to obtain perspectives on potential developments of shipping as well as help to prioritise impacts and guide subsequent research. Next, an ecosystem services approach is used to assess potential future changes to essential services to human well being. This also includes an assessment of human health as it is impacted through air emissions from shipping. Three case studies focusing separately on air emissions, water emissions and noise are used to conduct a detailed assessment of these pressures and their potential impacts on ecosystem services and human health. Finally, a costs based approach focusing on the costs of technologies and measures to avoid or reduce environmental pressures leading to degradation is used. Results are provided monetarily when possible, otherwise provided quantitatively or qualitatively.

2.1 Stakeholder consultation

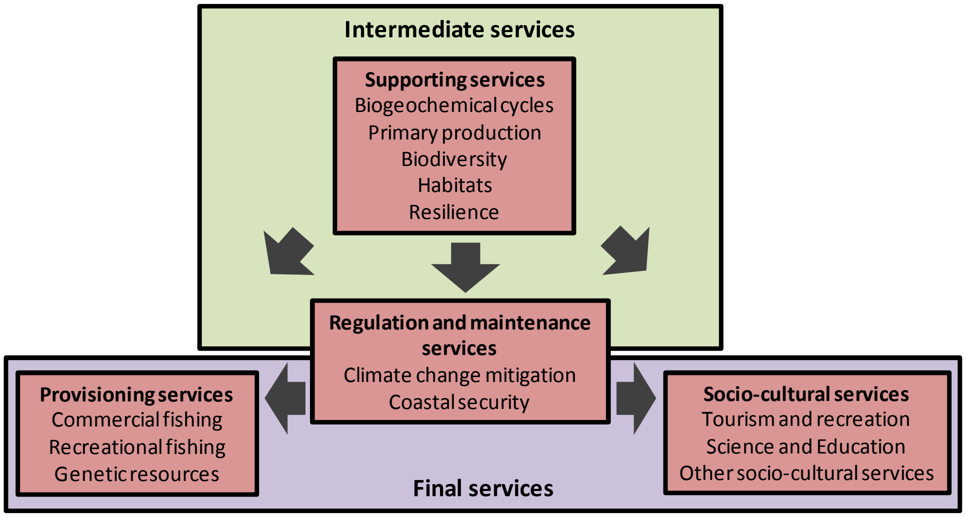
For the socioeconomic analysis on cost of degradation by shipping in the Baltic Sea, potential changes to relevant pressures, the state of the environment as well as human well being (including ecosystem services) need to be identified. To get an indication, stakeholders were consulted regarding their expertise on potential changes during a workshop in Tallinn (October 2016). During the workshop participants filled out a questionnaire. In the questionnaire they indicated if they expect that pressures, changes to the environment and impacts to human well being (i.e. ecosystem services) are increasing, stagnating or decreasing until 2030 and ranked the different items according to their relevance. The participants presented the answers and discussed between them. Stakeholders were selected and invited based on their knowledge and expertise of the overlapping issues (e.g. shipping, conservation, policy). The participating stakeholders came from public research institutions, public information agencies and maritime authorities. The results of the stakeholder consultation are included in section chapter 3.1.

2.2 The ecosystem services approach

2.2.1 The ecosystem services concept

The ecosystem services concept and approach reveals the dependencies between ecosystem services, defined as the final outputs or products from ecosystems that are directly consumed, used (actively or passively) or enjoyed by people (Fisher et al., 2009; Haines-Young and Potschin, 2013; Maes et al., 2013), and the ecosystem structures (or components), processes and functions underpinning them (see EEA, 2015a for detail on service generation). The ecosystem services approach is a way to integrate in assessments how functioning ecosystems support societal welfare (i.e. human well being) which is otherwise left out of the analysis. Not fully including ecosystem services can potentially lead to the effect that they are undervalued in their importance for society and are not adequately integrated in political decision making processes as well as resulting measures and instruments. Ecosystem services can be evaluated in order to include the services not only qualitatively, but also as much as possible quantitatively into decision and policy making.

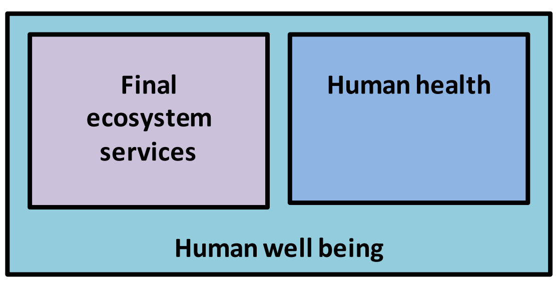
Figure 2: Examples for marine ecosystem services in the Baltic Sea



Source: Based on EEA, 2015a, HELCOM,2010b, Ahtiainen & Öhma, 2013, CICES, 2013, Millennium Ecosystem Assessment, 2005.

As Figure 2 shows, ecosystem services can be classified in the categories supporting, provisioning, regulating and cultural services. All these services affect different constituents of human well being, such as human health, basic material for good life, social relations and freedom of choice and action (Millennium Ecosystem Assessment, 2005). Human well being needs a society with sufficient social, human and natural capital and manufactured capital. Trade-offs and exchanges exist between these kinds of capital. The sustainable well being of a community depends on the ecosystem services flow and the distribution of benefits and costs (McMichael et al, 2005). BONUS SHEBA is measuring the direct influences by shipping on welfare and further well being. The assessment of human well being in BONUS SHEBA is based on the delivery of final ecosystem services and human health (see Figure 3).

Figure 3: Assessment components of human well being



Source: Authors

Indirect effects such as access to schools or work which are as well relevant for human well being are left out of this assessment, as a minor effect from shipping is assumed. The cut off as to how far indirect effects are included are based on available data, relevance and reliability of linkages, e.g. for commercial fishing fish processing industry is included as they are a major economic factors, for tourism and recreation accommodations for tourists are included as well.

Supporting services set the basis for other ecosystem services. They are not used by humans directly. But marine life depends on the flow and cycle of different materials such as nitrogen, phosphorus and oxygen. Primary production, habitats and biodiversity maintenance are examples for supporting ecosystem services. Primary production is the basis for the food chain in the Baltic Sea, e.g. the production of plant material through photosynthesis. The Baltic Sea provides a range of habitats like e.g. beds of mussels, sea-grass beds. A high level of biodiversity in general also supports a large variety of ecosystem services as a buffering function to increase ecosystem's resilience against e.g. meteorological events, accidents with contamination of hazardous substances as well as input of invasive species.

To avoid double counting (see also below) the ecosystem services are divided into intermediate and final services, see Figure 2 above. Intermediate services are the basis for delivery of the final ecosystem services. Supporting services are always intermediate services. Regulating services may be final or intermediate services. Provisioning and cultural services would then always be final ecosystem services (UK NEA, 2011).

Provisioning services

Provisioning services in the Baltic Sea can be described as all material and biota which represents tangible outputs from marine ecosystems. These can be consumed or traded. They can be further split in nutrition (outputs that can be used as food e.g. seafood) such as commercial fishing and recreational fishing and material (marine biotic material that is used for manufacturing goods) such as genetic resources. Relevant for the Baltic Sea are genetic resources and ornamental resources (EEA, 2015a, HELCOM, 2010b, Ahtiainen & Öhman, 2013, CICES, 2013, Millennium Ecosystem Assessment, 2005). In particular, humans directly benefit from provisioning services through commercial fishing activities, recreational fishing and genetic resources.

- *Commercial fishing* - Commercial fishing is the activity surrounding the catching of fish and other seafood for commercial profit. This activity is largely done in order to provide food, both in the fishers' home country and around the world. In addition to directly supporting fishers and fishing operations, indirect value is also generated for supporting activities such as processing operations, fish markets, and storage and transportation operators.

- *Recreational fishing* - In addition to commercial fishing, recreational fishing (i.e. for sport and leisure) is an important activity in the Baltic Sea region. This entails boat fishing and shore fishing using rod (i.e. pole) and line (i.e. no passive gears such as gillnets). Within the Baltic, recreational fisheries generally target cod, salmon, sea trout, garfish, herring, flounder and flatfish. This sector also contributes to local tackle shops, tackle manufacturers, bait suppliers, marine operators, and specialised angling media, angling tourism and other related business (Spahn, 2016).

- *Genetic resources* – Provisioning services also include genes and genetic resources which are used e.g. for pharmaceuticals today or potentially in the future.

Regulation and maintenance services

Regulation and maintenance services are the effect of marine biota and ecosystems on outputs of the ecosystem that affect the well being of individuals, communities or populations but are not consumed. These services comprise the neutralization or removal (mediation) of waste, toxicants or other nuisances, the mediation of flows and the maintenance of physical, chemical and biological conditions. The mediation of waste by marine biota or ecosystems has a detoxifying effect to the marine environment, examples are filtration, storage or accumulation by algae, plants or animals or mediation of smells, noise or visual impacts by the marine ecosystem. The mediation of flows include the stabilization and control of erosion rates, coastal flood protection as a control of liquid flows as wells as air ventilation and transpiration. The maintenance of physical, chemical and biological conditions contributes to sustainable human living conditions, such as pest and disease control, habitat and gene-pool protection and seed and gamete dispersal, soil formation and composition, chemical conditions of salt water, regulation of micro- and regional-climate as well as global climate regulation (EEA, 2015a, HELCOM, 2010b, Ahtiainen & Öhman, 2013, CICES, 2013, Millennium Ecosystem Assessment, 2005). Regulation and maintenance services primarily benefit humans in the Baltic Sea region through climate change mitigation and coastal protection.

- *Climate change mitigation* – The Baltic Sea acts as a sink for carbon dioxide (CO_2), therefore contributing to mitigating global climate change and its effects (Ahtiainen & Öhman, 2013).

- *Coastal protection* – Natural defence mechanisms provide important benefits to coastal populations, natural landscapes and infrastructure and will be increasingly important in contributing to climate change adaptation such as by providing security against storms (as well as providing beaches for tourism and recreation) (Ahtiainen & Öhman, 2013).

Socio-cultural services

Cultural services include outputs from marine ecosystems that have spiritual, intellectual, cultural, physical or experiential significance. They are non-material. These are physical and experiential interactions with marine biota, such as diving or snorkelling. Furthermore, interactions relating to science, education, entertainment or heritage as well as spiritual and religious benefits. (EEA, 2015a, HELCOM, 2010b, Ahtiainen & Öhman, 2013, CICES, 2013, Millennium Ecosystem Assessment, 2005). In terms of directly benefiting humans, this includes tourism and recreation as well as other socio-cultural services.

- *Tourism and recreation* - Major destinations of tourists on the Baltic Sea are the coasts of Germany, Sweden and Denmark, while tourism is considerably less in absolute numbers in Estonia, Latvia and Lithuania but the Baltic coast is the most important tourism destination in the three Baltic countries. This benefits numerous additional activities, ranging from tourist operators, to hotels, restaurants and other services.

- *Other socio-cultural services* – This includes culture and heritage as well as educational and research related activities.

Human health

Human health, while not an ecosystem service, is dependent upon a healthy environment and functioning ecosystem. This is therefore directly linked to local and regional air quality and affected by shipping. In particular, air pollution can lead to both acute and chronic effects on human health, which affect a number of different systems and organs. It ranges from minor upper respiratory irritation to chronic respiratory and heart disease, lung cancer, acute respiratory infections in children and chronic bronchitis in adults, aggravating pre-existing heart and lung disease, or asthmatic attacks. In addition, short- and long-term exposures have also been linked with premature mortality and reduced life expectancy.

There are different critiques against the ecosystem services approach, e.g. that the approach is to anthropogenic, while intrinsic values of nature are excluded (i.e. Redford & Adams, 2009), ecosystem services which have direct impact on human welfare are highly evaluated (i.e. Fairhead et al., 2012) and the possibility of double counting with regard to aquatic ecosystems exists e.g. including linked supporting services and final services twice (Fisher et al., 2011). At the same time, the ecosystem services approach is regarded as highly valuable to cover multiple effects of single pressures (Schröter et al., 2014). Double counting can be limited if the services are differentiated in intermediate and final services and only final services will be taken into account for the assessment, see above e.g. providing services and cultural services are always final ecosystem services, regulating services are partially final services (UK NEA, 2011).When weighing the critiques and counter arguments, the ecosystem services approach remains a useful approach to include environmental outputs and to "translate" them into a harmonised approach in order to make them comparable for economic and policy considerations. As outlined by Turner et al. (2010), the approach is also useful to highlight synergies and trade-offs between services as far as possible. This therefore supports with the selection of policy measures, and different beneficiaries may be impacted.

2.2.2 Assessment approach

The ecosystem services analysis is divided in a first part based on literature screening and a second part based on case studies. The first part of the assessment conducted here is based on literature review and builds on the stakeholder consultation. The literature review focuses on the economic evaluation of ecosystem services for the Baltic Sea and specifically on services which are influenced by shipping. Using the literature, we establish the link between pressures influenced by shipping, the changes to state of the environment and influence on human well being. The assessment is develop qualitatively and indicates if a certain emission or contaminant (pressure) increases, decreases or has a neutral effect on human well being until 2030/2040. The analysis is applied to the different single scenarios and cumulative scenarios designed for SHEBA (see Fridell et al., 2016).

For the different categories of DPSIR, the relative importance of shipping was analysed. The relative importance is based on the relevance of shipping on the DPSIR-categories compared to other sources, e.g. non-indigenous species are mainly brought into the Baltic Sea by shipping therefore the relative importance of shipping for this pressure is high. The relative importance is a good indication if policy actions are necessary for a certain pressure of shipping or if policy reactions should be at first focusing other policy fields. Furthermore, the economic importance of different types of human well being is included. This indicates relevance for economic activities, can be locally or for the whole Baltic Sea region.

Additionally, for a more detailed assessment, three case studies were developed. The first focuses on air emissions from shipping vessels and the impact this has, particularly on human health (see section 3.2.4). The second looks into emissions to water, and how this has potential impacts on cod spawning and ultimately fish stocks in the Baltic Sea. A final case study explores underwater noise from shipping in the Baltic Sea and its potential effects on fish and marine mammals. The case studies are focusing on pressures from shipping with the highest effects, as it was suggested by the literature review and stakeholder consultation (i.e. in Hamburg and Tallinn). Emissions to air and water are two of the major impacts of shipping on the environment and human health. Underwater noise was chosen because the pressure is an emerging issue although it is relatively under-researched and there is also a lack of data on the subject.

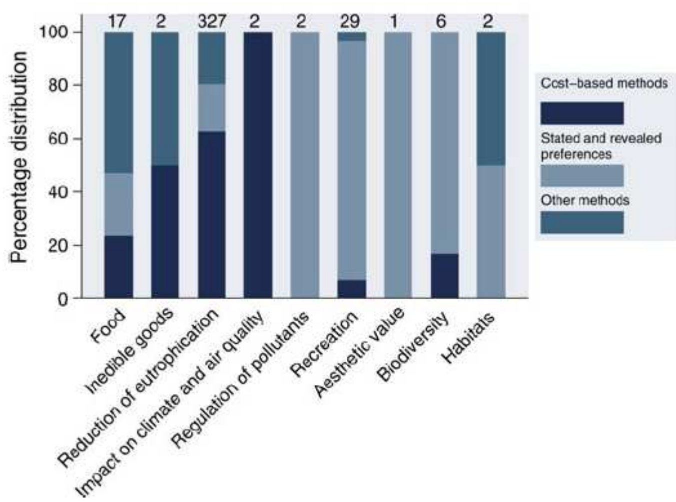
Pressures from shipping and their links to changes in the state of the environment and human well being were screened and included in both the literature based assessment as well as for the detailed assessment in the case studies. At the same time, to ensure all relevant ecosystem services were included, a further screening started with an overview of types of human well being (including different ecosystem services) and indicated if they are linked to mentioned changes to the state of the environment influenced by shipping.

2.2.3 Economic valuation

Ecosystem services and human health can be evaluated in economic terms. There are two different types of values which are included in such an assessment: use and non-use values. Use values are based on the actual use of the environment. Non-use values are not associated with a present use. Non-use values of marine and coastal spaces relate to aspects such as maintaining future opportunities e.g. for fishing, tourism, education and aesthetic experiences (Angulo-Valdes and Hatcher, 2010), but also the value of knowing that marine and coastal spaces are protected for future generations as well as for the flora and fauna that live there (Kumar, 2010). These issues are cross cutting.

A variety of economic valuation studies on marine ecosystem services in the Baltic Sea have been conducted. Sagebiel et al. (2016) produced a review of 76 studies on Baltic marine ecosystems. The most studies concentrate on one ecosystem service and used one method. One third of the studies focused on all riparian countries, two thirds focused on one country, only three studies were conducted for a smaller group of two or three countries. As shown in the Figure 4 the by far most studied ecosystem service in the Baltic is eutrophication, followed by recreation and food.

Figure 4: Number of studies for different ecosystem services



Source: Sagebiel et al., 2016.

For the case studies different valuation methods are used. Market prices based on market data for the water emissions case study, for which the value of cod catches was estimated. Benefit transfer was used for the case study on air emissions. We have used values from existing studies and transferred them according to established benefit transfer procedures. There is a debate in literature about the valuation of mortality risk for air emissions differentiating between two approaches: using Value of life years (VOLY) or the Value of statistical life (VSL). The VSL has been used some decades and shows the prevented fatality. VOLY specifies changes in life expectancy by using a value per life year. Both approaches are used in the literature therefore we use both for our evaluation, similar to other projects such as ClimateCost or the Clean Air For Europe (CAFE) programme. The values from the literature are based on people’s willingness to pay from stated and revealed preference techniques. They are based on surveys or e.g. on observed expenditures. For other components, market data was used e.g. for cost of medicine and care (Holland et al., 2011, Holland et al., 2015, Holland et al., 2013).

2.3 The abatement costs approach

2.3.1 Shadow price

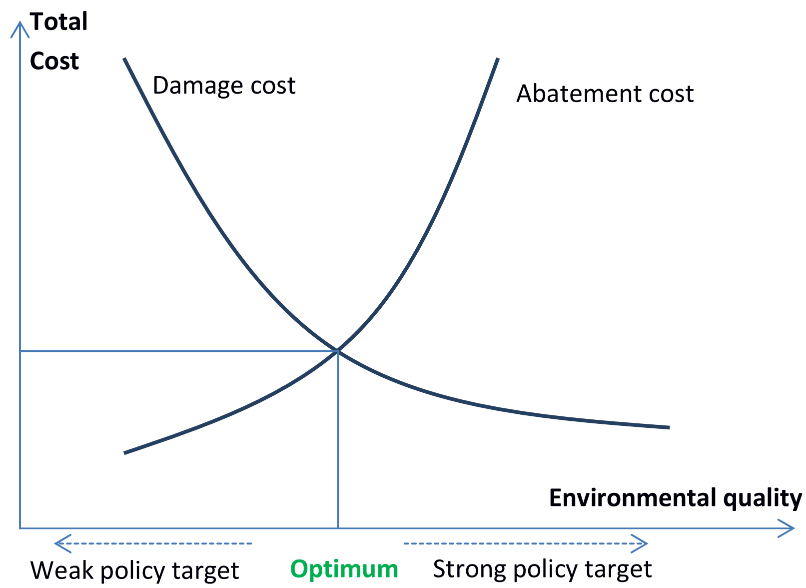
Pollution is an undesirable outcome of human activities. The extensive level of pollution causing damage to human health and natural resources is the result from market and regulatory failures (Hanley & White, 2002; Tietenberg & Lewis, 2016). Economists use the specific concept called *externalities* to describe this issue of market and regulatory failures. Externalities can be either positive or negative. A positive externality occurs when the activities improve the well-being of the society (e.g. when one individual walks to work, this reduces CO_2 emissions for all of society), whereas a negative externality will result in a reduction of the welfare (e.g. driving a car to work increases CO_2). Negative environmental externalities occur when the polluter does not fully bear the costs of the damage for which they are responsible. Shadow prices are constructed prices for goods or production factors that are not traded in the markets and can be used to weight impacts and therefore indicate environmental quality to society (Bruyn et al., 2010a).

The prevention and mitigation of these externalities (i.e. pollution) at local, regional and global levels need the proper set of environmental policies and must aim to maximize the well-being/welfare of the entire of society (Tietenberg & Lewis, 2016). The environmental policy has impacts on human well-being by two opposite dimensions: the growth of economy and environmental quality. Without proper assessment, a strong policy target could reduce economic growth while increasing the environmental quality and vice versa. Therefore, the environmental policy target should be set at an optimal level so that the total society's welfare is maximized taking both of these factors into account (Tietenberg & Lewis, 2016; Hanley & White, 2002).

Theoretically, the optimal level of pollution is determined by solving a system of equations including damage cost and abatement cost functions (Bruyn et al., 2010a). Damage costs refer to any type of economic loss caused by the pollution. Damage costs may be from negative impact of pollution on human health, productivity, biodiversity, agricultural crops and other economic activities. Abatement costs refer to the expenditure on mitigating pollution levels or production lost from the policy of improving the environmental quality.

Figure 5 illustrates the non-linear relationship of environmental policy targets with abatement and damage costs. A strong policy target achieves a high quality of the environment and prevents the damage costs of pollution; however, the strong target will increase abatement costs. In economic terms, the optimal point is where the abatement cost and damage cost curves intersects.

Figure 5: Illustrations of damage and abatement cost curves, in relation to policy target

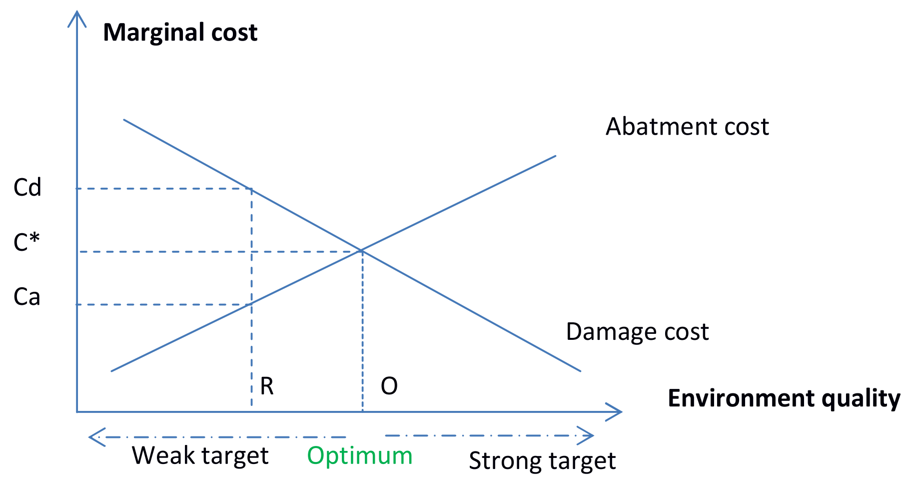


Source: Authors

The optimal level of pollution, which is referred to in economic terms as Pareto-optimality, results in the maximum total welfare for society (Bruyn et al., 2010a; Tietenberg & Lewis, 2016).

In Figure 5 the point at which marginal costs of abatement equal the marginal cost of damage due to pollution are the optimum and associated cost is termed as *equilibrium price*. The equilibrium price indicates the true (hypothetically) economic value of pollution if all externalities are internalised. Although such a price can in principle be developed and used to assign a monetary value to emissions, it is not generally done. The main reason is that such prices only report the external costs of a particular activity to society if the current pollution level is optimal. However, in most cases the environmental quality is not located at the optimum because of a lack of effective environmental policies (Bruyn et al., 2010a).

Figure 6: Optimal level of pollution and associated shadow price depending on policy targets



Source: Authors

Figure 6 presents a situation in which the environmental policy is weak and the environmental quality is at R. The marginal abatement cost at Ca is below the optimal cost and the marginal damage cost at Cd is higher than the equilibrium price. Because not all externalities are internalized, one cannot derive the equilibrium price (Bruyn et al., 2010a; 2010b). In this case one can derive a *shadow price*. Technically, the shadow price is the value of the *Lagrange* multiplier at the optimal solution, which means that the shadow price is the infinitesimal change in the objective function arising from an infinitesimal change in the constraint (Bruyn et al., 2010a; Tietenberg & Lewis, 2016). If there are no constraints, the shadow price is equal to the equilibrium price.

Therefore, in the real situation, e.g. pollution level R, two shadow prices can be obtained:

- A shadow price expresses marginal damage cost (Cd) which is derived from the damage cost function and equal to the infinitively small increase (decrease) in damages due to an infinitely small decline (increase) in environmental quality.
- A shadow price expresses marginal abatement cost (Ca) which is derived from the abatement cost function and equal to the infinitely small increase (decrease) in abatement cost due to an infinitely small increase (decline) in environmental quality.

Shadow prices from both methods describe a value for the (marginal) change in the condition of the environment to society. In the situation illustrated in Figure 6, the abatement cost approach gives the marginal cost to society of policy efforts to *maintain* environmental quality R, while the damage cost approach gives the marginal cost to society of small *deviations* from environmental quality R.

In practice, a shadow price is estimated by optimizing the demand function for environmental quality (Bruyn et al., 2010a). This demand is driven by the ability of people to pay for that quality. In other words: how much of their income would they be willing to sacrifice to obtain an additional unit of environmental quality. This is commonly referred to as the Willingness to Pay (WTP). Another approach is to consider the extent to which people are willing to accept environmental damage (Bruyn et al., 2010a; Hanley & White, 2002).

There are two general method categories available for estimating WTP: stated preference and revealed preference methods (see a review of Bruyn et al., 2010a). Stated preference methods (e.g. contingency evaluation, choice experiment) use questionnaires to assess people's WTP for maintaining or improving environmental quality. The revealed preference methods (e.g. hedonic price analysis, distance function approach) are used in some cases where value for environmental quality can be measured by using other markets as proxies for the non-existing market for environmental quality. If house prices are lower in polluted areas than in cleaner ones, an implicit price for environmental quality is provided by property price differentials. If the treated and untreated water prices are observed, implicit prices for removing specific pollutants are estimated by optimizing distance function.

This report is not an attempt to estimate the shadow price for pollution released by shipping. The aim is to calculate the total abatement costs for obtaining the environmental policy targets. The abatement costs are calculated using the level of pollution estimated in other WPs of the SHEBA project (WP2, 3 and 4) and shadow prices reported from previous studies.

Calculation methods

In this report abatement costs are calculated for individual pollutants released to air and water by different types of ships. These abatement costs should be understood as the economic values per year that the countries surrounding the Baltic Sea should be sacrificed to improve the environmental quality in accordance with the marginal shadow price defined in pervious section. Because the shadow prices are calculated by previous studies using abatement cost functions or damage cost functions the abatement costs in this report may be understood as the costs of externalities caused by shipping activities per year.

The abatement cost calculated at the average levels of pollution and average shadow prices are:

$$AC_{i,s} = \sum \sum_{i=1,s=1}^{n,S} M_{i,s} P_i$$

Where

$AC_{i,s}$ is abatement cost of pollution *i* caused by ship type *s*

$M_{i,s}$ is amount of pollutants (contaminants) *i* caused by ship type *s*

P_i is shadow price on average of pollutant (contaminant) *i*

Taking into account uncertainties of input data of pollution level and shadow price, the abatement cost of pollution *i* caused by ship type *s* are calculated by following equations:

$$AC_{i,s} = \int_t^T M_{i,s} P_i d_M d_P$$

The total abatement costs (TAC) of all ship types and pollution types are the sum up of abatement costs AC

$$TAC = \sum_{i=1,s=1}^{n,S} AC_{i,s}$$

Data of shadow price

The conceptual framework for constructing and understanding shadow prices are presented in the previous section. We collect the shadow prices of air emissions and water contaminants from previous studies.

Because the shadow prices are reported from various studies in different years, it is necessary to convert to a base year, using a discount rate of 2.5 % per year (Bruyn et al., 2010a; 2010b). The base year used is 2014. Table 2 and Table 3 present the shadow prices of air emissions and water pollutants that were converted to 2014 values. Beside the average value, max, min and standard deviation values are also reported, indicating the uncertainties and used for sensitive analysis.

Table 2: Shadow prices of air emissions

	Shadow price (EUR/tonnes, 2014 value)[(a)]					Uncertainty (%) of emission level [(b)]
	Max	Min	Average	Std.Dev	Sources	
CO2	58.0	23.2	33.6	11.9	Bruyn *et al* (2010a; b); Lee & Zhou (2015).	10%
CH4	784.0	724.8	739.6	25.5	Bruyn *et al* (2010a)	100%
N20	10,800.2	6,480.4	8,640.0	1,520.7	Bruyn *et al* (2010a)	60%
HC	5,844.9	2,783.3	4,314.1	866.8	Bruyn *et al* (2010b)	30%
CO	264.4	10.4	137.4	154.9	Bruyn *et al* (2010a)	30%
PM	57,984.7	2,667.3	20,903.5	5,409.3	Bruyn *et al* (2010a;b) Miola et al., (2009).	50%
SO2	11,596.9	1,855.5	6,272.0	1,610.6	Bruyn *et al* (2010a;b) Lee & Zhou (2015); Miola et al., (2009)	20%
NOX	11,596.9	2,435.4	7,667.2	1,484.5	Bruyn *et al* (2010a;b)	30%

[(a)] *Original values from different sources are averaged and converted to 2014 value with discount rate of 2.5%.*

[(b)] *Basing on the experts'judgement*

Table 3: Shadow price of water contaminants

	(EUR/tonnes, 2014 value) [(a)]			
	Max	Min	Average	Sources
Arsenic (As)	844,256.8	327,033.5	499,441.3	Bruyn *et al* (2010a;b)
Cadmium, Cd	5,241,814.3	133,364.7	3,537,838.1	Bruyn *et al* (2010a;b)
Cobalt, Co	5,065,540.9	1,688,513.6	3,377,027.2	Bruyn *et al* (2010a;b)
Copper, Cu[b]	4,134,886.9	1,378,295.6	2,756,591.3	Bruyn *et al* (2010b)
Dibromochloromethane, CHBr2Cl[b]	8,523,746.6	2,841,248.9	5,682,497.7	Bruyn *et al* (2010b)
Lead, Pb	444,162.6	47,547.4	179,752.5	Bruyn *et al* (2010a;b)
Mercury, Hg[b]	13,096,997.6	4,365,665.9	8,731,331.7	Bruyn *et al* (2010b)
Naphthalene, C10H8[b]	8,280.2	2,760.0	5,520.1	Bruyn *et al* (2010b)
Nickel, Ni[b]	2,494,500.5	831,500.2	1,663,000.4	Bruyn *et al* (2010b)
Nitrogen, N	25,513.3	5,334.6	12,060.8	Bruyn *et al* (2010a;b); Hernández-Sancho et al., (2010)
Phosphorus, P	8,735,970.5	8,697.7	624,489.9	Bruyn *et al* (2010a;b); Hernández-Sancho et al., (2010)
Pyrene, C16H10[*]	692,337.0	230,779.0	461,558.0	Bruyn *et al* (2010b)
Zinc, Zn[*]	393,136.1	131,045.4	262,090.7	Bruyn *et al* (2010b)

[(a)] *Original values from different sources are averaged and converted to 2014 value with discount rate of 2.5%;*
[(b)] *the Max and Min values of these pollutants are calculated at 150% and 50% of the average value, respectively.*

Pollution data

Pollution data for water, air and noise are estimated and prepared in other WPs of the BONUS SHEBA project (WP2, 3 and 4). The projected data for 2030, 2040 and scenarios are based on the data of future forecast as prepared in the BONUS SHEBA project. For the detailed data of pollution please refer to Fridell et al. (2016) the report on Future Scenarios.

Ships are grouped into 13 ship types and the emissions are estimated for each ship type. Emissions to air are estimated for 8 major elements including CO_2, CH_4, N_2O, HC, CO, PM, SO_2 and NO_X. Water pollution is estimated for 13 contaminants (compounds), including Arsenic (As), Cadmium (Cd), Cobalt (Co), Copper (Cu), Dibromo-chloromethane (CHBr2Cl), Lead (Pb), Mercury (Hg), Naphthalene (C10H8), Nickel (Ni), Nitrogen (N), Phosphorus (P), Pyrene (C16H10), and Zinc (Zn).

Air emissions in BAU

As mentioned above nine air emissions are estimated. Appendix Table A1 presents the amount of all air emissions by ship types for the different scenarios. We briefly describe NO_X emissions here as one of the major emissions. Figure 7 presents the amount of NO_X emission caused by shipping in 2014, 2030 and 2040 in the *BAU scenario*. The improvement in shipping technology leads to the decrease of NO_X emission in 2030 and 2040.

Figure 7: The amount of NO_X emissions caused by shipping in Baltic Sea in BAU scenario

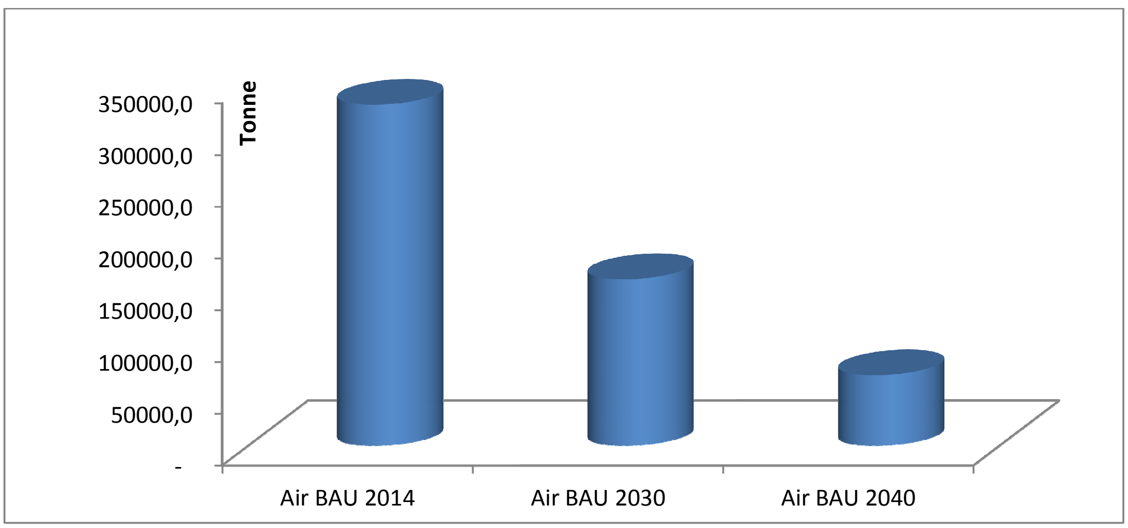


Figure 8: NOX emission shares of ship types for BAU in 2014

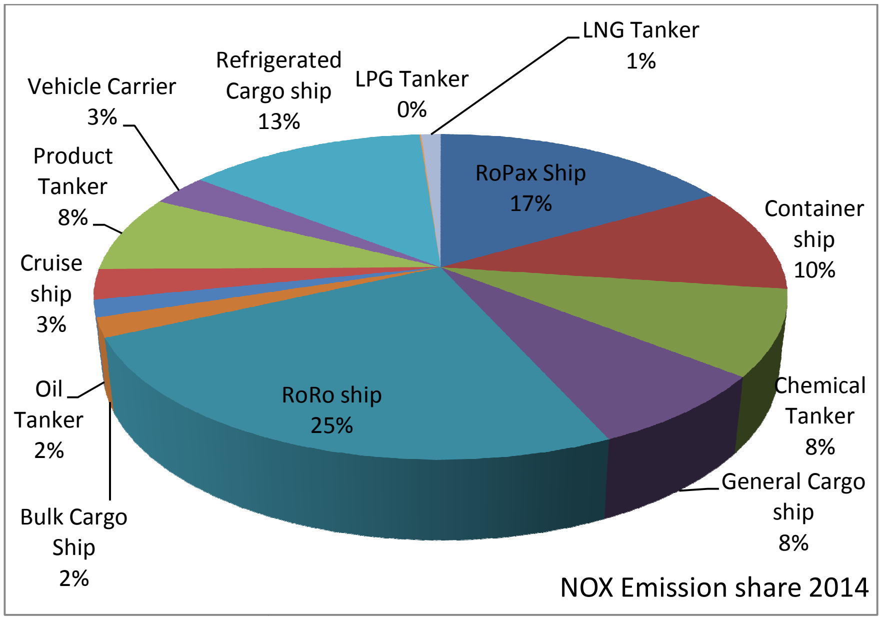


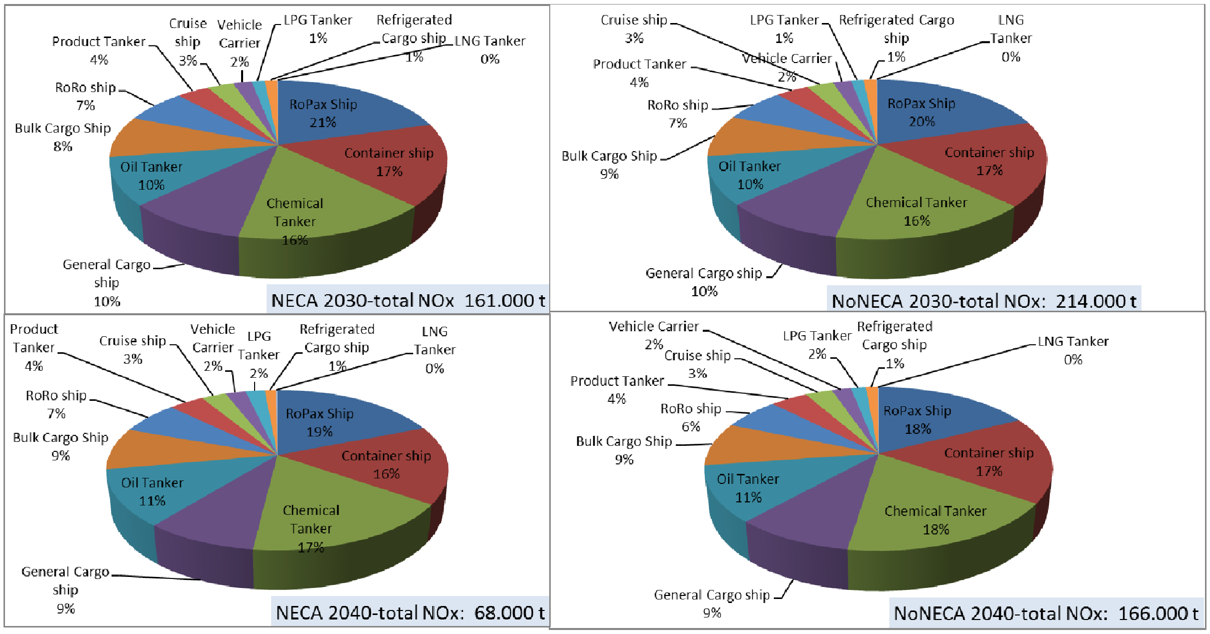
Figure 8 present the NOX emission in 2014 made by ship types. RoRo ship made the largest share of total amount NOX emission (25 %), the next is RoPax ship (17 %) and Refrigerated cargo ship (13 %). These three ship types represent over 65 % of total NOX emission.

Air emissions in single scenarios

We selected for the assessment the two developed single scenarios which show the highest impact on air emissions: *NECA/NoNECA 2021* and *LNG scenarios*.

The *NoNECA 2021 scenario* is built on the assumption that old ships are not replaced by new ships after year 2021 so that the NO_X emissions are significantly higher compared to the implementation of the NECA in 2021. The NECA policy was integrated in future prediction of BAU. Figure 9 presents total NO_X emissions by NECA and NoNECA in 2030 and 2040. With NECA implementation the NO_X emission will decrease by 33 % in 2030 and 44 % in 2040, in comparison with *NoNECA2021 scenario*. The share of NO_X emissions between ships types are not changed significantly between the *NECA and NoNECA scenarios* for 2030 and 2040.

Figure 9: NO_X emission Shares by ship types for NECA/NoNECA Scenario



Using Liquefied Natural Gas (LNG) as fuel in ships lowers emissions of sulphur dioxide (SO_2), particles and nitrogen oxide (NO_X) to air compared to operations on marine gasoil or heavy fuel oil. The *LNG scenario* is constructed on the assumption that LNG engines are the preferred alternative to diesel engines, for a significant share of ship owners from an economic point of view.

Figure 10: NOX emission shares by ship types for LNG scenarios

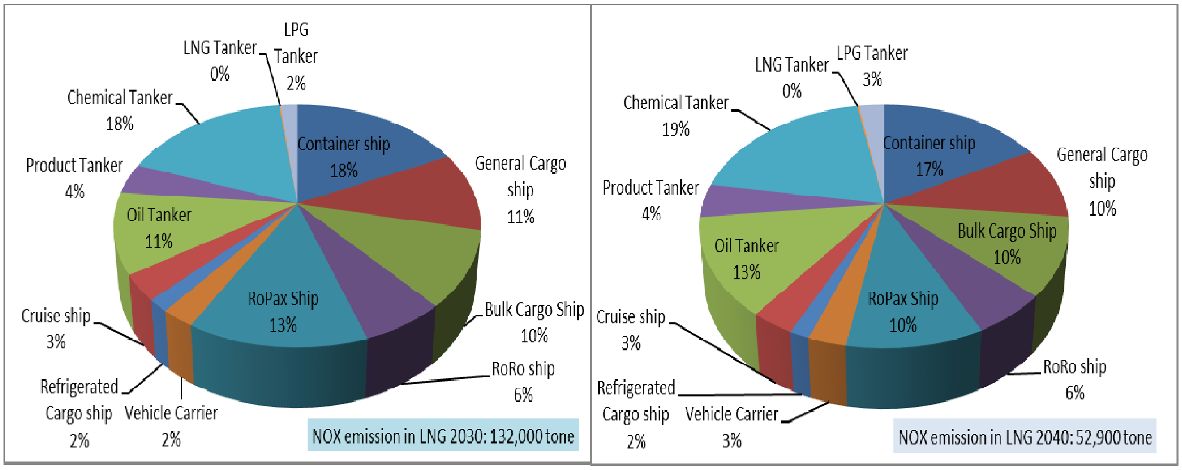


Figure 10 presents the NO_X emission made by *LNG scenario* in 2030 an 2040. Chemial tanker, container ship, RoPax ship and oil tanker create the large the NO_X emission, which the amount of these ship types accounts for over 60 % of total NOX emission.

Water pollution

Like air emissions, water contaminants have different effects on the environment. Copper compound, which are mainly emitted by anti-fouling paints, is the costliest to ecosystem accounting, nearly 90 % of total abatement costs in the BAU. Figure 11 presents amount of copper emission to the Baltic Sea in 2014, 2030 and 2040 for the BAU. The amount of copper emissions will increase by 14 % from 2014 to 2030 and 7.6 % from 2030 to 2040.

Figure 11: Copper emissions by BAU shipping

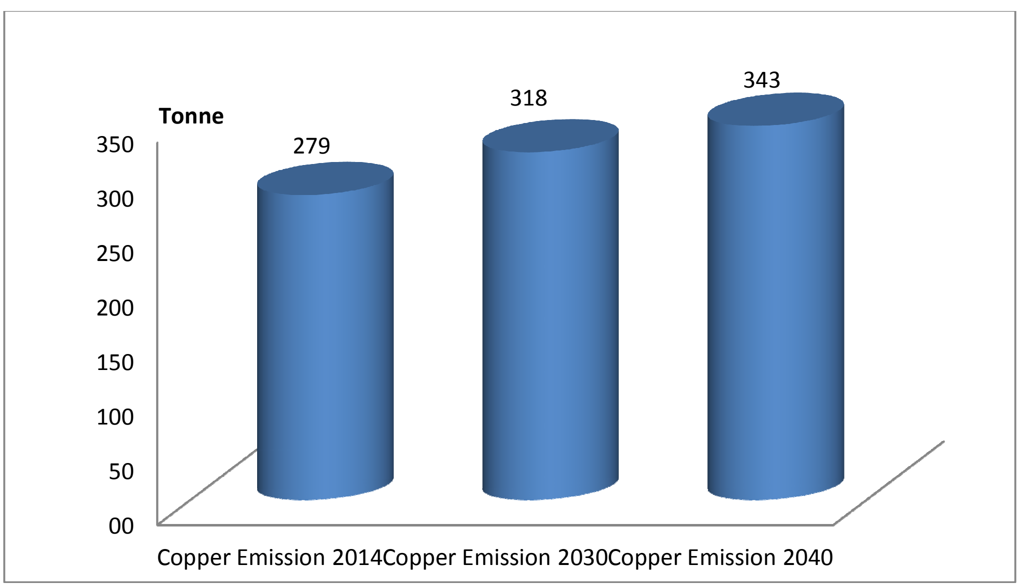
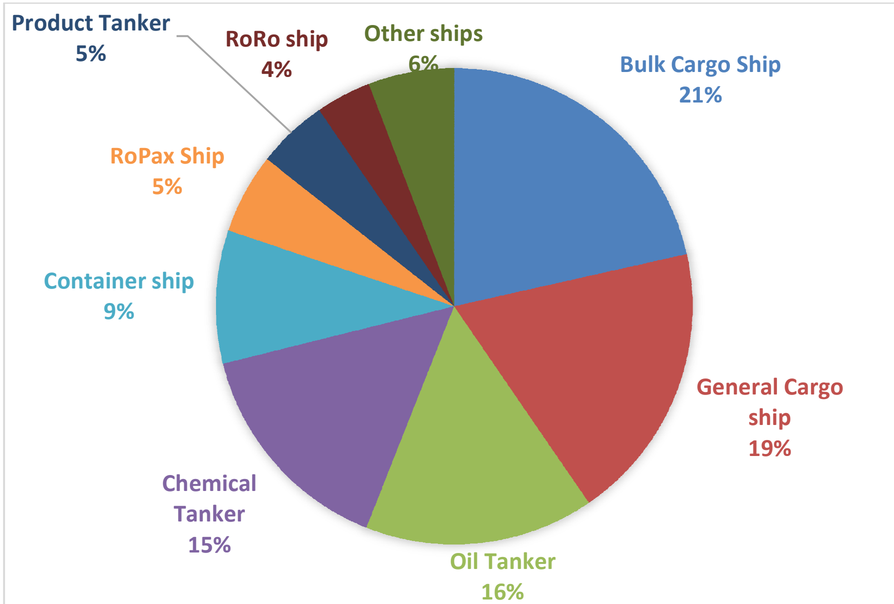


Figure 12: Copper emissions by ship types in 2014 for BAU



Bulk cargo, general cargo, chemical tanker, toil tanker and container ship create the large amount of copper pollution, as shown in Figure 12. These ship types cover of about 80 % of total copper amount in 2014.

Figure 13: Copper emissions by ship types for scenarios of no-water emission and slow steaming

Figure 13 presents the share of copper pollution emitted by different ship types for two scenarios: *No-water emission* and *slow steaming*. In general, bulk cargo, oil tanker, general cargo and container ship create the large amount of copper pollution.

3 Shipping in the Baltic: Costs of degradation

The following chapter reports the assessment of the costs of environmental degradation to the marine environment, as well as the impacts on human health following the approaches as described above. Therefore the chapter includes the results from the stakeholder workshop, the ecosystem services approach, and the costs based approach.

3.1 Stakeholder feedback

The filled questionnaires from the SHEBA Workshop in October 2016 are summarised in this chapter. Particpating stakeholders are coming from science, policy and businesses relevant to shipping in the Baltic Sea region. The participating stakeholders ranked potential changes to relevant pressures, the state of the environment as well as human well being (including ecosystem services). They indicated as well if they assume an increase, stagnation or decrease of pressures, changes to the environment and human well being.

For the assessment of pressures, the answers show that air pollution was ranked from almost all stakeholders as a high priority (see following table, different answers by row). Furthermore, participants indicated water contaminants as relevant. With marine litter selected as a third priority pressure. Acidification, underwater noise, invasive species and nutrients (in air and water) were mentioned but only by individual participants.

Table 4: Priorities for pressures indicated by interviewed groups

Stakeholder group	First priority	Second priority	Third priority	Notes
1	Air pollution	Invasive species	Water contaminants	Additions: Accidents, spills
2	Air pollution	Marine litter	Acidification	All three pressures are the most relevant to humans
3	Underwater noise	Water contaminants	Marine litter	
4	Water contaminants	Air pollutants		
5	Nutrients (connected air + water)	Marine litter	Noise	

From the pressures, only underwater noise was assessed as increasing in the years up to 2030. Air pollution is mainly indicated as decreasing due to political and technology developments. Furthermore, water contaminants and marine litter were mainly identified as pressures, which will stagnate until 2030. But for marine litter, the picture is not fully clear as individual answers range from decreasing to increasing. Nutrients (nitrogen and phosphorus) and acidification are described as decreasing, but for both pressures some participants also indicated them as stagnating and increasing. For invasive species no clear trend can be described as the same number of people indicated decreasing and stagnating.

For the assessment on the potential changes to the state of the environment food web structure change was mentioned as a priority from all participants. Acidification was also indicated by almost all. By a minor group of participants, eutrophication was selected as a priority. Many changes to the environment are indicated as stagnating until 2030, including the high priorities: food web structure change and eutrophication. For eutrophication, the participants' opinions were spread as also a decreasing development was indicated. Acidification got even a further division of answers, equally mentioned as increasing and decreasing.

Table 5: Priorities for changes to state of the environment

Stakeholder group	First priority	Second priority	Third priority	Notes
1	Acidification	Food web structure	Eutrophication	Highest increase noise, because no regulation in place
2	Acidification	Air pollution	Food web structure/biodiversity	n.a.
3	Food web structure	Particle Matters (PM)	Humidity in the air	Coupled effects: nitrification, noise concentration, food web structure/biodiversity

Note: Stakeholder groups 4 and 5 did not fill this table.

For change to human well being and ecosystem services, clean air in cities is prioritized by most participants as most relevant followed by clean air in the whole Baltic Sea region. Clean water was mentioned as well by several participants. Agricultural production (on land), weather and climate and marine life were mentioned by individual interviewees as important. The development of the impacts over time were only indicated by a very limited number of participants, as increasing impacts were slightly indicated for impacts on human health and impacts due to change in water availability.

Table 6: Priorities for changes to human well being and ecosystem services

Stakeholder group	First priority	Second priority	Third priority	Notes
1	Clean air in cities	Clean air in Baltic Sea region	Agricultural production (land)	n.a.
2	Clean air in cities/ Baltic Sea region	Clean water	Weather, Climate Change	n.a
3	Clean air	Clean water	Marine life	n.a.

Note: Stakeholder groups 4 and 5 did not fill this table.

Especially, for change to environment and change to human well being the interviewees described that they have difficulties to judge priorities according to their knowledge and experiences. Nevertheless, the results of the stakeholder workshops can give some indication but should be considered with caution.

3.2 Ecosystem services assessment

This section describes the results of the ecosystem services assessment for shipping in the Baltic Sea. The chapter covers the pressures by shipping, links to change of state of the Baltic Sea and the influences on human well being.

3.2.1 Pressures caused by shipping

Pressures can be differentiated in between acute and ongoing pressures. Acute pressures are those such as oil spills caused by sea-related accidents. According to a HELCOM report 150 ship accidents occurred in the Baltic Sea area in 2013, which was the highest number compared to the last 10 years (HELCOM, 2014a). Other pressures are ongoing or constant, such as the release of toxic substances via anti-fouling paint. Other pressures could be located between these poles, since their characteristics show, that they are neither constant nor acute. Discharge of ballast or bilge water to the sea or other legal or illegal discharge of substances by ships would be such pressures.

Emissions to air

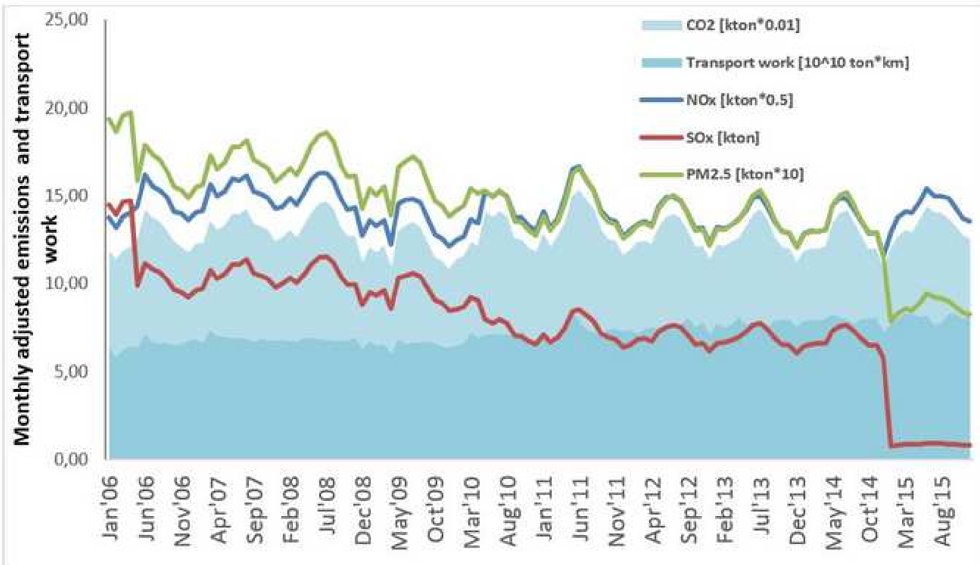
Emissions to air from shipping are mainly nitrogen oxide emissions (NO_X), particulate matter (PM) and sulphur oxides (SO_X)., Shipping also contributes to air pollution by emission of volatile organic carbon (VOC) compounds, CO, polycyclic aromatic hydrocarbons (PAH) and metals. These primary air pollutants react in the atmosphere and contribute further to air pollution with ozone, secondary particulate matter and other secondary air pollutants such as peroxy-acetyl nitrate (PAN), other organic nitrates or formaldehyde and other oxygenated hydrocarbons. Shipping is also source of greenhouse gases (GHG) with CO_2 causing most of the climate forcing originating from shipping (Eyring et al., 2010). These emissions are mainly connected to combustion of marine fuel in the ship engine. In some cases the contribution from engine lubricants may be important as well. The influence of CO_2 and short lived climate pollutants as pressures leading to climate change is not covered in detail, as this is considered a global pressure relevant beyond the Baltic Sea region and out of the scope of this assessment.

Sulphur emissions consist mainly of sulphur dioxide which is oxidised to sulphate in the atmosphere. The emissions are directly related to the fuel sulphur content. Emissions of NO_x consist to ca. 95 % of nitrogen monoxide (NO) with the rest being nitrogen dioxide (NO_2). The majority of the emitted nitrogen originates from atmospheric molecular nitrogen oxidised in the engine. Depending on fuel, ca. 10 % may originate from the nitrogen content of the fuel (Moldanová et al., 2009). NO_x emissions are mostly related to the combustion conditions and the highest emissions occur under high engine loads. In a relatively clean atmosphere, which is the case in a majority of the marine regions, NO is within few minutes oxidised to NO_2 by ozone. NO_2 is further oxidised to nitric acid (HNO_3) which can either deposit on surfaces, or can form nitrate as part of particulate matter.

Direct emissions of particulate matter (primary PM) are also mostly related to the combustion of marine fuels and to some extent also to the lubricants, however, the formation is affected both by the fuel composition and by the engine's operation mode. Fuels with high fuel sulphur content lead to higher PM emissions (e.g. Moldanová et al., 2013, Zetterdahl et al., 2016), at the same time high PM emissions are related to low and transient engine load conditions. Particulate matter emitted by ships is largely dominated by nanoparticles (size range 10-100 nm) and the main constituents of the particles are organic carbon, elemental carbon (also called black carbon or soot), sulphate and ash containing metals. In general, PM is emitted to air. If scrubbers are installed, part of the particles are emitted to water via the scrubbing water. In the atmosphere gas phase air pollutants from the ship's exhaust react and contribute to the atmospheric load of PM forming secondary particulate matter. The secondary PM related to ship emissions consists mainly of secondary organic aerosol (SOA), sulphate and nitrate. Even with low sulphur fuel (0.1 % S content) the secondary PM derived from the fuel sulphur may be higher than the directly emitted PM. If all sulphur in a marine fuel with 1% S content would be oxidised into sulphuric acid (H_2SO_4) and this would condense on particles in the ship plume, one would get an emission factor for particulate sulfate of 30.6 g/kg fuel. The plume studies (Jalkanen et a., 2015) have shown that between ~1 % (polluted urban air, winter conditions) and 60 % (clean background, summer conditions) of the emitted SO_2 contributes to the PM, giving $EF(H_2SO_4{\cdot}nH_2O)$ between 1 and 40 g/kg fuel. These numbers are comparable to the typical emission factors for PM which are a few g/kg fuel.

According to estimations by the STEAM model, run by the Finnish Metrological Institute (FMI) (Johansson & Jalkanen, 2016), the total emissions to air from shipping in the Baltic Sea in 2015 were 342,000 tonnes of NO_X, 10,000 tonnes of SO_X, 10,000 tonnes of PM, 23,000 tonnes of CO and 15.9 million tonnes of CO_2 (from all vessels). The CO_2 emissions correspond to 5.0 million tonnes of fuel, of which 26 % was associated to auxiliary engines. RoPaX vessels, tankers, cargo ships and container ships contributed most to the emissions. Based on the fuel consumption, the vessel types have a share of RoPaX vessels with about 25 % of fuel consumed, tankers with about 22 %, cargo ships about 18 % and container ships about 15 % (Johansson & Jalkanen, 2016).

Figure 14: Development of ship air emissions in the Baltic Sea during the period 2006-2015 (including seasonal variations)



Source: Johansson & Jalkanen, 2016
Note: *CO_2 and transport work are shown as area plots.

Note: All monthly values have been corrected for AIS-coverage and normalized according to the total amount of days in the month. Note, that PM emissions do not contain the associated water.

Figure 14 shows the development of the air emissions from ships in the Baltic Sea from January 2006 to August 2015. The SO_X and PM emissions decreased significantly by -88 % (SO_X) and -36% (PM) (2006-2015) while the cargo volume increased slightly from 2010 to 2015. The reduction is due to the stricter SO_X emission regulations of the MARPOL Convention in the Baltic Sea SECA area.[2] Beside seasonal variations NO_X and CO_2 emissions are stable during the period 2006 and 2015 (Johansson & Jalkanen, 2016). In Figure 15 you can see the spatial distribution of SO_X emissions in the Baltic Sea. Due to traffic lines there are hotspots in the Gulf of Finland, Kattegat Bay and the Danish Straits and between Sweden and Germany.

[2] From January 1st 2015, only 0.1% sulphur or less was allowed in marine fuels.

Figure 15: The geographical distribution of SO_X emissions from Baltic Sea shipping in 2015

Source: Johansson & Jalkanen, 2016.
Note: Emissions are reported in kilograms per grid cell.

Compared to other air emission sources in the EU, the 'non road transport' shows importance for NO_X, SO_X and PM emissions according to EEA (2016), analysing all EU Members States (EU28). For the year 2014, NO_X-emissions from shipping have a share of 4 %, for SO_X emissions shipping is contributing 2 %, and shipping has a share of 1 % at $PM_{2.5}$ and PM_{10} compared to all other sources in EU 28 (EMEP/CEIP, 2014). The annual NO_X emissions from ships in the Baltic are equal to all land based NO_X emissions of Denmark and Sweden combined (Madjidian et al., 2013). An assessment for Denmark also shows that SO_X emissions from shipping in North Sea and Baltic Sea waters surrounding Denmark exceed by far the Danish land based emissions. The assessment was was done before the SECA cup was introduced (The Danish Ecocouncil, 2011).

EEA (2013) compared the current and projected air emissions from international shipping with land based emissions in the EU27. They conclude that current land based emissions exceed ship emissions by far, e.g. in the year 2000 land based emissions of NO_X and PM[3] were spectively more than three and ten times higher than emissions from shipping in all European Seas.[4] But according to emission projections, NO_X emissions in 2030 will almost be equal between land based emissions and shipping emissions, and be only five times higher for PM. The changes are mainly based on reductions of land based emissions between now and 2030 due to different policy measures. The picture is different for SO_X emissions of shipping which are already decreasing due to policy regulations. Therefore, the political interest regulating NO_X and PM emissions from shipping is expected to increase during the next years (EEA, 2013, EEA, 2016, Campling et al, 2013).

[3] Especially referring to $PM_{2,5}$

[4] For both emissions shipping in the Baltic Sea contributes by approximately 10% to the emissions of all European Seas.

Non-indigenous species

In addition to emissions to air, shipping also creates pressures through emissions to water. Non-indigenous species are spread with ballast water and ship hulls. Ballast water is required by ships as they travel in order to stabilise them and support manoeuvrability. As ships are required to operate at a certain weight, ships take on ballast water as way to compensate for unloading cargo or using fuel. However the release of ballast water facilitates the transfer of aquatic organisms as well as human pathogens across marine areas (Matej et al., 2017). The global shipping industry is therefore contributing to ocean biodiversity loss through transfer of such organisms. It is estimated that in 2011, about 250 million tonnes of ballast water was discharged into the Baltic Sea (HELCOM, 2014b). This water can include (potentially invasive) species, such as certain species within the groups: Zooplankton (500um), Phytoplankton (10um), Bacteria or Invertebrate larvae. These organisms are emitted to water during discharge of untreated ballast water (Ojavee & Kotta, 2015) and during hull cleaning due to biofouling on ship hulls.

Contaminants to water

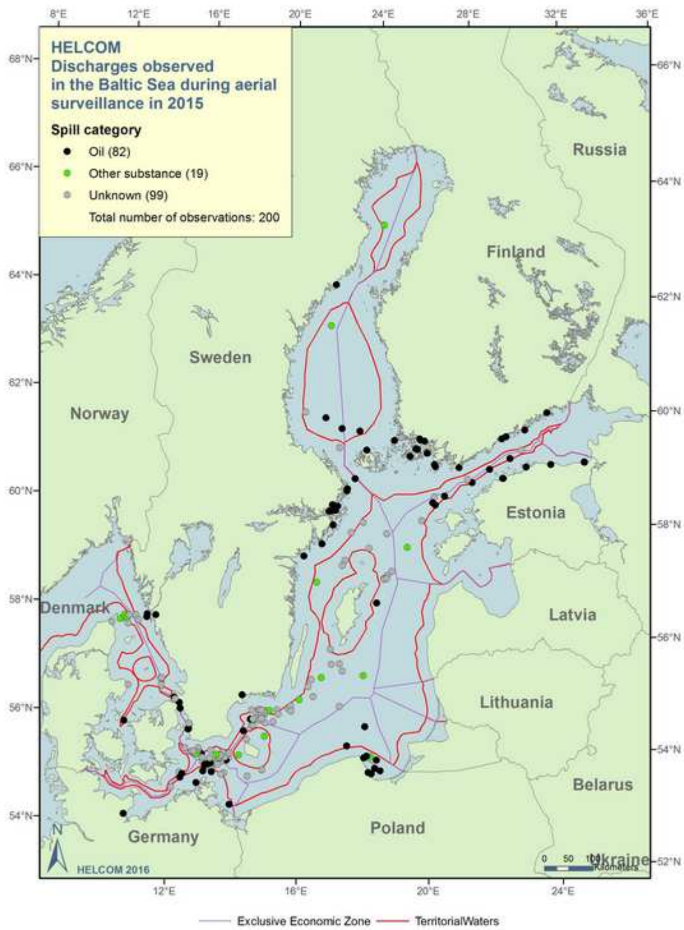
In addition to non-indigenous species, emissions to water are in general discharged from ballast water, grey water, sewage, bilge water, scrubber water and antifouling paint. Nutrients are emitted into water primarily through grey water and food waste as well as potentially through both treated and untreated ballast water (Hassellöv et al., 2016). Bilge water as well as grey water and black water also contains numerous contaminants. This includes: polycyclic aromatic hydrocarbons (PAH) emitted into water via stern tube oil and bilge water; metals emitted via scrubbing and bilge water i.e. copper (Cu), zinc (Zn), chromium (Cr), cobalt (Co) and lead (Pb); tensides are emitted into water via grey and bilge water; pharmaceuticals; and particles such as plastics from debris and waste (Hassellöv et al., 2016). Nutrients are of importance as they lead to eutrophication in the Baltic Sea, with the major contributing elements nitrogen (N) and phosphorous (P). In general, waterborne and airborne annual inputs of nutrients to the Baltic Sea amount to about 977,000 tonnes (t) of nitrogen and 38,300 tonnes of phosphorus. The mentioned total input includes average annual atmospheric deposition of nitrogen of about 218,600 tonnes (HELCOM, 2013a), Baltic Sea shipping contributing 6 % to these annual athmospheric nitrogen deposition.

The use of antifouling paints to reduce biofouling on ship hulls leads to the emission of toxic antifouling substances. Antifouling paints can be classified in three main groups/generations, after the substances used: first generation copper-based, second generation organotin-based, and the new, third generation, organotin-free antifouling paints (Fernandez & Pinheiro, 2007). Substances include: copper (Cu); zinc (Zn); copper pyrithione (CuPT); zinc pyrithione (ZnPT); dichlorooctylisothiazolinone (DCOIT); zineb (ZINEB); which are preventing to colonization of macroalgae (e.g seaweed); microalgae (benthic) and bacteria (soft fouling organisms) and barnacleas and tube worms (hard fouling organisms) (Hassellöv et al., 2016) on the hull. The different components of antifouling paints can show synergistic effects with each other or other water contaminants (Fernandez & Pinheiro, 2007).

Oil spills

Oil spills are detected through aerial surveillance. The development of the number of oil spills shows a clear decline during the last fifteen years. Long-term trends show that also the size of the soil spills is decreasing. In 2015, it reached an all time low of 82 mineral oil spills and has mainly (98 %) a maximum size of one cubic metre (see Figure 16). But half of the detected spills are other or unknown substances.

Figure 16: Discharges observed in 2015



Source: HELCOM (2016).

Based on national reports HELCOM summarized reported accidents with and without pollution, including collisions, groundings, fires. 150 accidents were reported in 2013, from these only six showed any pollution. The number increased during the last years, from 130 accidents in 2010. The accidents happened mainly close to shore (in ports or during approaching a port). Ten percent of the involved vessels were tankers which are the major issues of concern (HELCOM, 2014a). The last large oil incidents in the Baltic Sea happened in 2001 and 2003. In 2001 a large spill with 2,700 tonnes of oil was at Kadetrenden in Denmark. The accidents in 2003 happened close to Bornholm between Denmark and Sweden and had an oil spill of 1,200 tonnes (HELCOM, 2017a).

Underwater noise

Amongst the kinds of anthropogenic energy that human activities introduce into the marine environment, which includes sound, light, other electromagnetic fields, heat and radioactive energy, the most widespread and pervasive kind of anthropogenic energy is underwater noise (Van der Graaf et al., 2012). Anthropogenic sounds may be of short duration (e.g. such as from seismic surveys, piling for wind farms and platforms, or explosions) (Van der Graaf et al., 2012) or be long lasting (e.g. dredging and shipping) affecting organisms in different ways. Indeed, motorized shipping is “one of the most prominent man-made sources of underwater noise” (Madsen et al, 2006). Anthropogenic noise has different sources leading to different effects, depending upon its frequency range, intensity, and whether it is an intermittent, pulsed, or continuous sound (EEA, 2015a). Ship-related noise has numerous sources, such as the engine, propeller, pumps sonar or echo Madsen et al, 2006). The main source of noise from ships is from the engine operation (loud continuous noise from 10 Hz to 10kHz).

Physical impacts

Ship activities such as anchoring, mooring and ship movement potentially affect the seabed, including seagrass areas, which form an important coastal habitat providing nurseries, refuges and foraging areas for a variety of organisms (Hemminga and Duarte, 2000). Anchoring affects seagrass due to dropping the anchor (Francour et al., 1999) as well as dragging and recovering the anchor chain (Milazzo et al.,2004). Montefalcone et al. (2008) showed that the shoot and rhizome density of seagrass beds declines directly after anchoring. Besides dropping, dragging and recovering the anchor, swinging chain moorings have been shown to produce circular scars on the seagrass meadows chain (Collins et al., 2010).

Ship wakes potentially impact seagrass, but can also potentially contribute to shoreline erosion (Bourne, 2000; gaskin et al., 2003; Nanson, 1994). The effect differs according to the shipping speed and location characteristics. The latter is determined by physical (bay or open sea), and geographical characteristics (average natural hydrodynamic loads at the site). Especially, where several of these parameters are overlapping in a way that the impact of wave wash is multiplied, the respective hydrodynamic loads can be significant. For example, in the Tallinn bay area, ship-generated waves form, at least, about 5–8 % from the total wave energy and about 18–35 % from the wave power (Soomere, 2005). In that area, the periods of waves from wakes caused by high-speed ships are frequently much larger than periods dominated by wind waves, having a height of about 1m and a period of 10–15 s (Soomere, 2005). These wake waves lead to an increase of suspended matter in the water column of about 1 per square meter for about five minutes, which may result in an annual loss of 100 L of fine sediments from each metre of the coastal line (Erm & Soomere, 2004).

Summary of pressures from shipping

See Table 7 for a summary of the pressures from shipping. The relative importance of shipping describes the proportion of shipping compared to other drivers, e.g. agriculture or land based transport. + = low share compared to other drivers (minor driver), ++ = medium share compared to other drivers, +++ = high share compared to other drivers (major driver). The relative importance is based on expert judgements by the authors.

Table 7: Summary of pressures from shipping

Pressure		Relative importance of shipping	Type	Trend (based on literature)	Spatial dimension
Emissions to air	CO_2	+	Ongoing	Increasing	Global
	NO_X	++	Ongoing	Increasing	Local to regional
	SO_X	+	Ongoing	Decreasing	Local to regional
	PM	++	Ongoing	Increasing	Local to global
Emissions to water	Non-indigenous species	+++	Ongoing	Increasing	Local to regional
	Contaminants to water	+	Ongoing	Increasing	Local to regional
	Oil spills	+++	Acute	Decreasing	Local to regional
Noise emissions	Underwater noise	++	Acute and Ongoing	Increasing	Local
Physical impacts	Anchoring, mooring and movement and ship wakes	+++	Acute and Ongoing	Increasing	Local

3.2.2 Shipping induced changes to the state of the Baltic Sea

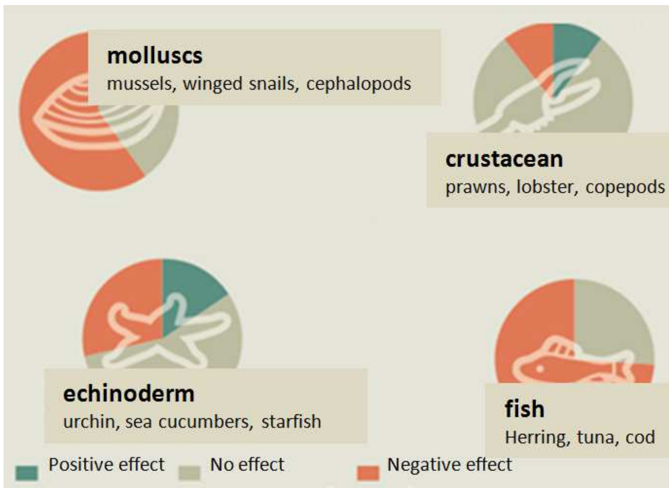
Air quality and effects on climate

The main impact of CO_2 emissions is an increase of radiative forcing and related global warming. The primary health effect related to SO_2 and NO_X from shipping is due to hazardous secondary particles formed by atmospheric reactions between SO_2 and other pollutants. Furthermore, NO_X emissions also contribute to the generation of ground-level ozone, which causes damages to vegetation and human health. Primarily emitted NO is converted to NO_2 which is a criteria air pollutant with negative health impacts. Furthermore, increase of NO_X emissions leads to eutrophication and can destroy especially oligotrophic ecosystems. PM is the prominent air pollutant with negative health effects including cardiovascular and plumonary diseases and cancer (WHO 2013a). Corbett et al. (2007) estimated that particulates emitted from ships cause 60,000 cardiopulmonary and lung-cancer deaths each year worldwide. PM affects the Earth's radiative balance; however, the impact is complex including both direct warming from dark particles as black carbon, direct cooling from bright particles as i.e. sulphate and complex secondary effects through impact on cloud formation. Climate impact of black carbon, both from shipping and other sources, is often discussed as it has strong direct climate warming effect. Some black carbon particles are transported to Polar Regions and are deposited at the inland ice where they contribute to ice melting; this effect is in particular discussed in connection with shipping in the Arctic (The Danish Ecocouncil, 2011, AirClim et al., 2011, Madjidian et al., 2013).

Ocean Acidification

Besides climate change, enhanced atmospheric concentration of CO_2 increases acidification of the oceans which has lethal consequences for marine ecosystems. Also SO_X and NO_X leads to acidification of the oceans but with minor importance compared to CO_2. Modeling of ocean acidification in the Baltic Sea suggests that pH units will decrease by 0.2-0.4 until the year 2100 (Havenhand, 2012). The reaction of most Baltic Sea species to ocean acidification are poorly understood, the most studies concentrate on single-species, single factor studies and are not including multiple stressors and interlinkages between the different species. However, experiment data show that a lot of key species in the food web of the Baltic Sea are very tolerant to pH changes which are expected to react only slightly (Havenhand, 2012). Major affects can be seen for larval stages of mussels and cod for which biologically significant negative impacts are covered. This is especially relevant as cod is one of the main species for the fisheries industry of the Baltic Sea area (Havenhand, 2012). In general, negative effects of acidification are mainly seen for mussels and fish, including herring, and to a bit less extent for echinoderms, e.g. sea urchin. For echinoderms and shellfish even positive effects are assumed, see Figure 17 (Heinrich Böll Stiftung, 2017).

Figure 17: Effects of acidification on different species



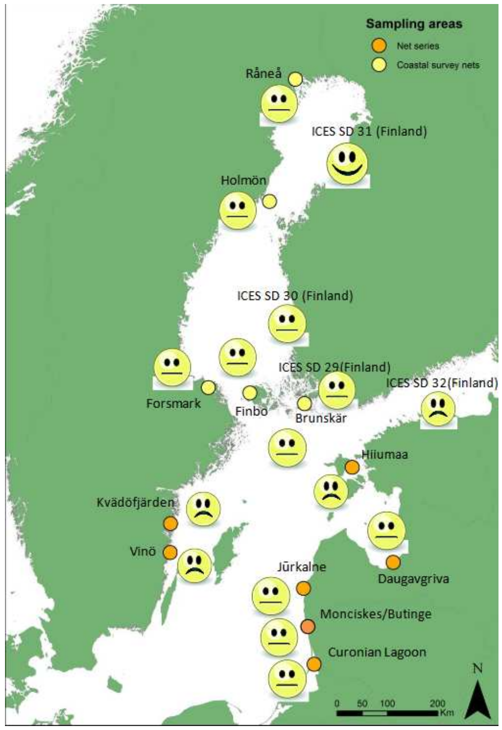
Source: Adapted, based on Petra Böckmann/Heinrich-Böll-Stiftung, Heinrich Böll Stiftung, 2017.

Fish stocks

HELCOM uses key species abundance to describe the environmental status of the Batlic Sea. Coastal fish communities are typically local in their appearance, so the evaluations of coastal key fish species are done on a relatively local scale. The estimates are based on fishery independent monitoring, surveys with recreational fishermen and statistics of commercial catches. Typical species considered by HELCOM are perch, flounder and cod (HELCOM, 2017b). The indicator on abundance of coastal key fish species based on perch and flounder see Figure 18. The measurements have shown that the abundance of perch[5] was stable during 1995 and 2011 in most coastal areas along the Gulf of Bothnia and Baltic proper. But there are diverse local developments. At the Finnish coast of the Gulf of Bothnian there has even been an increase. But at the Gulf of Finland, the Gulf of Riga (Hiiumaa) and in some Swedish areas at the Western Baltic Proper the abundances of perch have decreased. Perch was chosen for the measurement as it has an important role in structuring the coastal ecosystems in the Northern parts of the Baltic (Eriksson et al., 2009; 2011). Furthermore, it is an important species for small-scale fisheries at coast and for recreational fishing (HELCOM, 2013b). The abundance of perch can reflect changes in water temperature and eutrophication in coastal areas as well as changes in the level of exploitation or predation pressure (HELCOM, 2013b).

[5] Flounder for Monciskes/Butinge / (Lithuania).

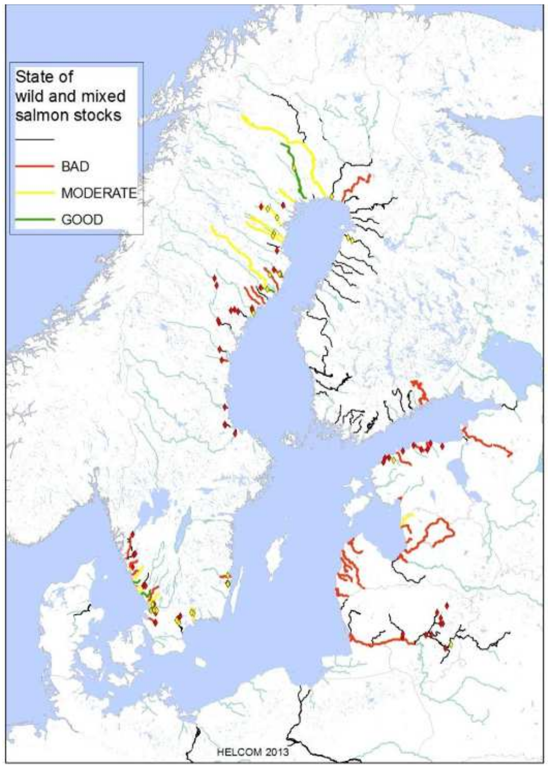
Figure 18: Abundance of key species between 1995 and 2011



Source: HELCOM, 2013b. A happy smile describes an increase of perch stocks, a neutral smile no change and a sad smile a decrease of perch stocks (for Monciskes/Butinge flounders were used.)

Another HELCOM indicator is focusing on the abundance of wild salmon, especially the young salmon – the smolt (see Figure 19). Salmon is one of the most important species for fishing in the Baltic Sea. The assessment is done in the rivers around Baltic Sea. The status of the smolt production is varying. In the northern Baltic rivers the stocks have improved (e.g. Bothnian Bay), but in the southern Baltic most of the rivers are far from reaching their potential. In the Gulf of Finland and the Baltic Proper, the smolt production is low and no improvement is seen. In the southern Baltic Sea, the smolt production is currently less than 30 % of their potential capacity. The situation of the poor status of the wild salmon stocks can be explained with multiple reasons: overfishing, eutrophication, local pollution and obstacles in the rivers, e.g. turbine mortality (HELCOM, 2013c, ICES, 2013).

Figure 19: Status of wild and mixed Baltic Sea salmon stocks



Source: HELCOM, 2013c.

Food web

HELCOM (2012a) assessed concentrations of contaminants in herring and showed different results across marine areas in the Baltic Sea. In regard to significant trends, the analysis (see Table 8) shows that there were several downwards trends for the relevant substances, mercury (5), copper (2), and zinc (1) (HELCOM, 2012a). Mercury showed significant downward trends in 5 areas (Kattegat N, Hanöbukt, Stockholm area, Gävlebukt, and Luleå area). Zinc showed increasing trends in two areas (Hanöbukt and Outer Gulf of Finland) and a decreasing trend in one area (Stockholm area). Copper showed an increasing trend in two areas (Hanöbukt and Gävlebukt) and a downward trend in two areas (Kattegat N and Stockholm area). The causes of the two upward trends in zinc are not clear (HELCOM, 2012a). The main anthropogenic sources of mercury are from general waste disposal (e.g. batteries) and industrial activities, with low quantities in fossil fuels. It is highly toxic and one of the most dangerous metals in the aquatic environment. Organic forms of mercury affect the nervous system, whereas the inorganic forms affect a range of cellular processes (EEA, 2015c).

Table 8: Temporal trends in contaminants measured in herring in the Baltic Sea (1980 – 2010)

Area		Mercury	Copper	Zinc
		Muscle	Liver	Liver
Kattegat N	r	-0.277	-0.361	0.014
	P	**0.0431**	**0.0124**	**0.925**
	n	22 (2010)	22 (2010)	22 (2010)
Hanöbukt	r	-0.475	0.334	0.361
	P	**0.0004**	**0.0189**	**0.0104**
	n	28 (2010)	26 (2010)	26 (2010)
Stockholm area	r	-0.497	-0.293	-0.343
	P	**0.0002**	**0.0437**	**0.0196**
	n	28 (2010)	25 (2010)	24 (2010)
Åland	r	-0.031	0.429	-0.619
	P	0.89	0.177	0.0509
	n	12 (2004)	7 (2004)	7 (2004)
Outer Gulf of Finland	r	0.126	-0.333	0.733
	P	0.499	0.348	0.0388
	n	16 (2004)	6 (2004)	6 (2004)
Inner Gulf of Finland	r	-0.244	0.2	-0.244
	P	0.1352	0.421	0.325
	n	20 (2007)	10 (2007)	10 (2007)
Gävlebukt	r	-0.638	0.296	0.127
	P	**<0.0001**	**0.0386**	**0.374**
	n	28 (2010)	26 (2010)	25 (2010)
Bothnian Sea	r	-0.309	-0.154	0.026
	P	0.0839	0.464	0.9
	n	18 (2010)	13 (2010)	13 (2010)
Bothnian Bay	r	-0.122	0.273	0.394
	P	0.389	0.217	0.075
	n	26 (2010)	12 (2010)	12 (2010)
Luleå	r	-0.355	-0.062	0.184
	P	**0.0072**	0.659	0.192
	n	29 (2010)	27 (2010)	26 (2010)

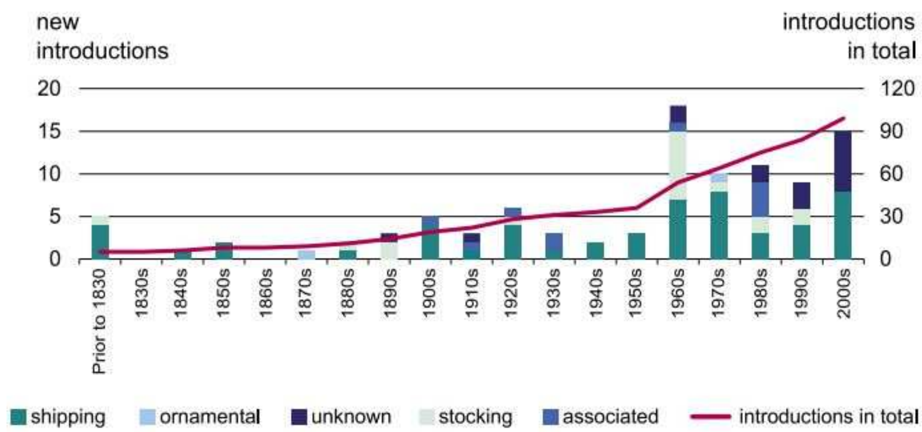
Source: HELCOM, 2012a.

NOTE: The results of the time trend analysis using a non-parametric Mann-Kendall test. For each area and substances the results of the test are given. All the chemical analyses for Heavy metals are done on liver tissue except for Mercury where the analyses are done on muscle tissue. Upper row (r): the Kendall tau correlation coefficient. Middle row (P): significance level. Lower row (n); number of observations (years) in the time series. The last year in the time series are indicated in parentheses. The significant upward trends are indicated by P-values shown in red while significant downward trends are indicated by P-values in green. The significance level of P<0.05 are used.

Invasive alien species

Figure 20 below shows the increase of invasive species in the Baltic Sea over time, while showing shipping as the primary source. According to HELCOM, there are about 118 non-indigenous species observed in the Baltic Sea and about 90 are established. Shipping is responsible for about 43 % of them (HELCOM, no date).

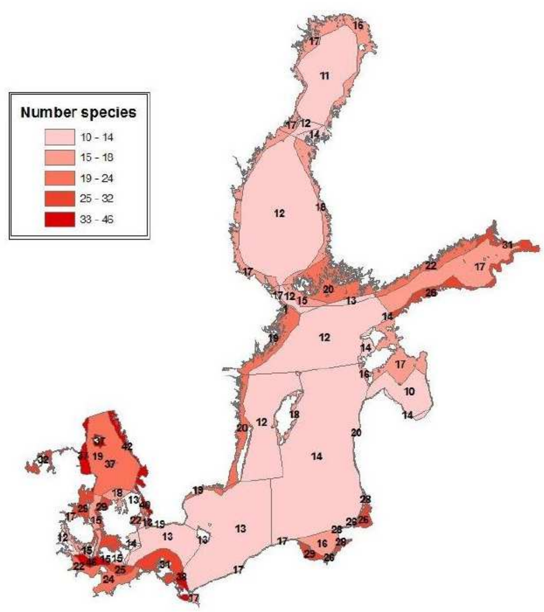
Figure 20: Invasive species observed in Baltic Sea over time



Source: HELCOM, 2014b.

The lowest number of non-indigenous species is observed in the Bothnian Bay, while the majority can be seen in the south-west of the sea as well as the Gulf of Gdansk and Gulf of Finland; see Figure 21 (HELCOM, 2012b).

Figure 21: Number of observed non-indigenous species in the Baltic Sea coastal and offshore areas



Source: HELCOM, 2012b.

According to the EEA (2015a), around 1-2 new species enter the Baltic Sea each year. Non-indigenous species, also known as alien species, are species introduced outside their natural environment. They are referred to as 'invasive alien species' (IAS) if they find adequate conditions to survive, reproduce, spread, and cause wide-spread harm to biodiversity and human livelihood. The impacts from IAS include reducing genetic variation and eroding gene pools as well as leading to the extinction of endemic species, and the alteration of habitat and ecosystem functioning. Their impacts are generally widespread and irreversible, although still poorly assessed.

Invasive alien species could lead to a decrease in fish stocks if they are threatening the food base of fish. An example for one species is the Chinese mitten crab. For the German Economically Exclusive Zone the damages for fisheries by the Chinese mitten crab (*Eriocheir sinesis*) were estimated at EUR 73.5-85 million (Estonian Ministry of Environment & SEI Tallinn, 2013).

There are indications that IAS also has an impact on biofouling at ship hulls. Fernandes et al. (2016) discuss that invasive species often show a higher average growth and resistance to pollutants or antifouling coatings compared to native species. Therefore, a higher appearance of invasive species could increase biofouling at ships. Since biofouling affects the fuel consumption, it also increases the costs for fuel and respective emissions. The estimated costs of mitigation measures, including anti-fouling measures and ballast water treatment systems are between 1.6 % and 4 % of annual operating costs depending on the type of ship (Fernandes et al., 2016).

Water quality

Water quality is influenced by several pressures of shipping, e.g. water contaminants or air emissions linked to eutrophication. Several studies related to shipping estimate a variety of impacts including water quality. The improvement of water quality with consequences for biodiversity, recreation (bathing water quality) and food (coastal cod stock level) was valued by Eggert and Olsson (2009) in a questionnaire with a willingness to pay of EUR 50 to 107 per person and year. Kosenius (2010) as well analysed the improvement of water quality with consequences on recreation, aesthetic values and food (algae blooms, increased bladder wrack population, abundance of coarse fish, and water clarity). The results show a willingness to pay of EUR 155 to 201 per person per year. For improved water quality and reduced noise and litter with links to habitats (supporting services) and reduction in eutrophication, Östberg et al. (2012) estimated between EUR 19 and 54 per person per year for Sweden.

Waste and litter

Marine litter is influencing several ecosystem services, especially tourism and recreation and other socio-cultural services, such as aesthetic values and natural and cultural heritage. Furthermore, it relates to commercial and recreational fishing as fish catches are influenced as litter objects can damage equipment and reduce commercial fish catches (Estonian Ministry of Environment & SEI Tallinn, 2013). Marine litter can damage propellers, block cooling water systems on fishing vessels, damage nets and destroy catches. The damages by marine litter were estimated with EUR 105,157 (one million SEK) per year at the West Coast of Sweden. The monetary value for the reduction of marine litter was estimated with EUR 57 (500 SEK) per household and year for the Swedish West Coast and EUR103 (900 SEK) per household per year for the Swedish East Coast (including different types of services) (Estonian Ministry of Environment & SEI Tallinn, 2013). Cleaning beaches due to marine litter was estimated by a survey of coastal municipalities in Latvia. For 300 km of Latvian coast EUR 183,931 (133,000 LVL) are estimated for costs of cleaning the beaches. 20 % of these costs were indicated for cleaning of algaes. The costs are estimated to be the mimimum (Estonian Ministry of Environment & SEI Tallinn, 2013).

Noise levels

Due to a lack of data and quantitative studies, it remains highly challenging to assess underwater noise caused by shipping and the impacts it has on the environment. The many different sources of noise make it difficult to determine the overall noise levels from shipping and whether this has been increasing. Marine organisms are affected unequally to the different frequencies, making it difficult to identify potential changes in behaviour. All fish can detect sound but there are species-specific differences in the sensitivity of hearing and in detection of the different components of underwater sound i.e. particle motion and pressure (e.g. Popper et al. 2014).

Fishes and invertebrates use sound e.g. in communication, seeking prey and avoiding predators, orientating with respect to environmental features, locating appropriate habitats and some also for navigating, so these functions are potentially vulnerable (Hawkins and Popper 2016).

All marine mammals use sound to communicate with conspecifics (i.e. member of the same species), find prey and perceive their surroundings. Underwater noise has the potential to cause direct and indirect impact on marine mammals through disturbance, masking important sounds, increasing stress levels and causing temporary or permanent shift in hearing sensitivity.

Moreover, it is possible that the timing (day vs night) would have different effects. For example, it could be expected that noise may impact species during sleeping periods differently than during day light period when actively feeding or spawning. Similarly, it can be expected that the duration (short vs long-term) of noise will have varying effects.

Research has shown that over the last 50 years there have been increases in ambient noise, mostly due to shipping activity (Van der Graaf et al., 2012). At the same time, it is recognized that underwater noise caused by shipping is likely to have adverse effects on the marine environment. Scientific results unequivocally suggest that animals react to sound and sometimes with devastating results (Van der Graaf et al., 2012) and a spectrum of possible impacts could be identified, which range from subtle effects (e.g. temporary reduction in hearing sensitivity, behavioural effects) to obvious (e.g. worst case, death) effects (see also Table 9) (Van der Graaf et al., 2012).

More commonly, noise leads to strong avoidance reactions. Marine mammals use sound for foraging, orientation, communication or to avoid predators (Tyack, 1998) and are therefore possibly susceptible to negative effects of man-made noise generated from constructing and operating large offshore wind turbines (Richardson et al., 1995). Hence, mammals and fish are using noise for relevant life-supporting actions and therefore sensible to noise interference or superimposition.

Table 9: Potential negative effects of sound on marine life

Type of impact	Impact of noise on organisms
Physiological, non auditory	Damage to body tissue: e.g. massive internal haemorrhages with secondary lesions, ossicular fractures or dislocation, leakage of cerebro-spinal liquid into the middle ear, rupture of lung tissue
	Induction of gas embolism (Gas Embolic Syndrome, Decompression Sickness, 'the bends', Caisson syndrome)
	Induction of fat embolism
	Disruption of gas-filled organs like the swim bladder in fishes, with consequent damage to surrounding tissues
Auditory	(Sound Induced Hearing Loss) Gross damage to the auditory system – e.g. resulting in: rupture of the oval or round window or rupture of the eardrum
	Vestibular trauma – e.g. resulting in: vertigo, dysfunction of coordination, and equilibrium
	Damage to the hair cells in fishes
	Permanent hearing threshold shift (PTS) – a permanent elevation of the level at which a sound can be detected
	Temporary hearing threshold shift (TTS) – a temporary elevation of the level at which a sound can be detected

Type of impact	Impact of noise on organisms
Perceptual	Masking of communication with conspecifics
	Masking of other biologically important sounds
Behavioural	Stranding and beaching
	Interruption of normal behaviour such as feeding, breeding, and nursing
	Behaviour modified (less effective/efficient)
	Adaptive shifting of vocalisation intensity and/or frequency
	Displacement from area (short or long term)

Source: Van der Graaf et al., 2012.

Due to the numerous factors at play, it is not possible to reflect underwater noise with one single indicator or data set. These factors also lead to a differentiation between noise impacts in acute effects (for short-term noise) and permanent or chronic effects (for long-term/continuous noise) (Van der Graaf et al., 2012). Short term continuous noise (30 minutes) to recorded noise from small vessels has been shown to increase cortisol levels in fish (Wysocki et al., 2006). This increases stress levels for the fish, which can potentially impact stocks and catches. Long-term continuous exposure (2 hours) from noise from small boats and ferries can additionally lead to hearing impairment and masking of natural communication between species (Scholik and Yan 2001; Vasconcelos et al., 2007). Furthermore, vessel noise potentially alter mammal and fish behaviour by provoking avoidance reactions (including altering swimming speed and direction) and altering schooling behaviour (Engås et al., 1995, 1998; Sarà et al., 2007). Harbour porpoises in the Baltic Sea were recorded to show strong behavioural responses to low levels of high frequency components in vessel noise (Dyndo et al., 2015). Bas et al. (2017) found evidence of vessel traffic impacting the behaviour of local Black Sea harbour porpoise (*Phocoena phocoena relicta*) in the Istanbul Strait. The porpoises were more likely to switch to another behavioural state when vessels were present, altering the behavioural budget of the porpoises. In the Scroby Sands, UK, harbor seals and grey seals were displaced due to high levels of construction noise (Skeate et al, 2012). Lack of recovery by harbour seals was suggested by the authors to be due to high levels of traffic in the area. Bagocius (2015) showed that shipping in the Baltic Sea has the potential to mask grey seal calls. In the analyzed samples, a ship as far as 500 meters away was shown to completely overlap the grey seal communication signal.

Several laboratory experiments have used vessel engine noise to examine noise impacts to fish in controlled environments (e.g. Scholik and Yan, 2001, 2002; Kastelein et al., 2008; Smith et al., 2004). In these studies, fish hearing returned to normal over time, but it appears that recovery time varies with the frequency of the sound and the duration of exposure. The amount of hearing loss appears to relate to how loud the noise is compared to the threshold of hearing at that frequency. The duration of noise exposure impacts the magnitude of temporary hearing threshold shift (TTS). Continuous anthropogenic sounds caused temporary hearing threshold shift in harbor porpoises at lower levels than intermittent anthropogenic sounds (Kastelein et al., 2016). In harbour seals the magnitude of the temporary hearing threshold shift increased with longer exposure to noise (Kastak et al., 2005).

Some studies suggest that there are also impacts of noise on other marine species such as crabs, mussels, sea urchins, white shrimp, spiny and American lobster, and perhaps squid (e.g., Iversen et al., 1963). In addition, a broader range of marine invertebrates may be impacted by reduced auditory awareness in conditions where shipping noise dominates bandwidths with important abiotic or biotic cues (OPSAR, 2009).

Oil spills

Concentration of contaminants, e.g. oil spills, are affecting water quality and clarity as well as biodiversity which influence the services commercial and recreational fishing. The long-term effect of an oil spill can also influence genetic resources as well as tourism and recreation and other socio-cultural values (Estonian Ministry of Environment & SEI Tallinn, 2013).

The effects of an exceptionally large oil spill (5,000–150,000 tonnes) are estimated to be EUR 5-16 million (Forsman, 2003, 2006, 2007). The costs of an oil spill are heavily depending on location, quantity of an oil spill and also the season during which the spill occurred. Estimations show that the cost of lost fishing days may be up to EUR 13 million for the Swedish Baltic Coast. The lost opportunity for recreation linked to beaches is estimated to be EUR 14 a day. But no data for the number of lost recreational days at beaches by an oil spill could be found. Furthermore, it is estimated that the willingness to pay to reduce the risk of an oil spill in the Gulf of Finland is about EUR 100 to 300 million. As this value is including user and non-user values it is also associated to natural and cultural heritage (Estonian Ministry of Environment & SEI Tallinn, 2013).

VTT (2009) evaluated the average cost of the oil spill in European waters with EUR 10,000 per tonne. Environment Research Consulting calculated a similar result, with cost of eliminating an oil spill for Estonia of 6,820 USD per tonne.[6] Furthermore, it is assumed that the annual turnover of fishery and marine related sectors could be influenced by an oil spill by one fifth of their turnover which could lead to a loss of up to 100 million Euros[7] for fisheries and tourism sector.

Tegeback & Hasselström (2012) evaluated the costs for major oil spill in the Baltic Sea as well. The study included direct (cleaning beaches), market (tourism, fisheries) and nonmarket costs (environmental costs). Depending on the location (two locations at the Swedish and one at the Polish coast were analysed), the costs ranged from approximately EUR 100 to 400 million. These cost estimates can help decide the level of preparedness for future oil spills, assess the effects from oil spills on fishing and tourism industries and also to the general public In the Baltic Sea.

Oil spills at the Lithuanian coast were analysed by Depellegrin & Blažauskas (2013). The authors used existing studies and based losses on the value of recreational services, marine ecosystem services, commercial fisheries and seabirds. The amount was about EUR 524 million per year. The estimates included the value of both intermediate and final ecosystem services and goods, and therefore double-counting is possible. Also, the study estimated the total economic value of the Lithuanian coastal zone and not marginal values. Therefore, the applicability of the value estimates is questionable.

Loss of biodiversity

Biodiversity loss is due to cumulative effects from a combination of different pressures, which could have very relevant consequences especially for the Baltic Sea as it has a low species diversity. Only a very limited number of species exist in the ecosystem compared to other marine areas (e.g. the North Sea). Single species fulfil important ecosystem functions in the Baltic Sea. The elimination of key-stone species which are having unique roles in the functioning of ecosystems can lead to highly relevant changes in ecosystems' structure and their related provided ecosystem services (Elmgren and Hill 1997, Johannesson et al. 2011). Especially prone are

[6] Adjusted to inflation, the result is 10,051 Euros per ton for 2009.

[7] Based on turnover of 2005.

species which are impacted by a variety of pressures. Furthermore, a loss of biodiversity is also linked to impacts on food web structures (see above).

The loss of biodiversity caused by shipping is linked to different pressures, analysed in chapter 3.2.1. The pressures having impacts on species diversity are especially water contaminants, e.g. copper, mercury, underwater noise from ship turbines, non-indigenous species, air emissions and physical impacts.

Erikson et al. compared the aquatic vegetation in 44 similar shallow and sheltered inlets with and without shipping activities. The results show that both recreational boating activities and traffic by medium sized ferryboats may lead to significant changes in community composition, species richness and the development of the macrophytic vegetation at greater depth. Increases in resuspension and turbidity by wake waves were stated as major factors contributing to the loss of biodiversity due to shipping (Eriksson et al., 2004).

The loss of biodiversity is influencing the supportive ecosystem service maintenance of biodiversity (according to Garpe's classification of ecosystem services, Garpe, 2008). This supporting service has an influence on all other final ecosystem services but with varying extent. A loss of biodiversity would most likely have an effect on the provisioning services: seafood and provision of genetic resources. Direct effects are also expected for cultural services, especially aesthetic values and recreation. But also inspiration, science and education and cultural heritage is expected to be influenced (Estonian Ministry of Environment & SEI Tallinn, 2013).

Ressurreição et al (2012) valued for Poland a willingness to pay for the prevention of species loss of 10 % (biodiversity) between 44 and 83 US$ (35 and 67 Euro) per person per year. It is mentioned, that the effect of a loss in biodiversity by shipping on the fishing industry is difficult to estimate and might need to be estimated on a case-by-case basis (Estonian Ministry of Environment & SEI Tallinn, 2013). The marine biodiversity of several sensitive species in the Baltic Sea is also at risk, because of imposex (the growth of male sex organs in female species), which is e.g. imposed by antifouling paint that contains tributyltin compounds (EEA, 2015a).

Coastal vegetation

Coastal vegetation is a major habitat providing nurseries, refugees and foraging areas for a variety of organisms including fish species (Hemminga and Duarte, 2000). Besides that, seagrasses reduce coastal erosion, improve water quality (Larkum et al., 2006) and absorbs the kinetic energy of currents and waves which impacts sediment deposition and retention (Widdows et al., 2008; Bos et al., 2007). Sundblad & Bergström (2014) analysed pike, perch and roach in the Stockholm archipelago - three of the common coastal fish species relevant for commercial and recreational fishing. The different fish species utilize shallow, sheltered near shore habitats during their first year of life. Boating is influencing habitat degradation and changes in habitat structure with effects on the vegetation community (Sundblad & Bergström (2014). The vegetation composition and cover probably changed through resuspension of surface sediments leading to turbidity. Studies describe that fish reproduction habitats in the vicinity of marinas and ferry routes produce fewer recruits than habitats which are pristine (Eriksson et al. 2004; Sandström et al. 2005).

Eutrophication

Eutrophication is caused by nitrogen through water and air emissions. Shipping is influencing the emissions, but there are as well large land based sources. Eutrophication influences directly the ecosystem services: commercial and recreational fishing, tourism and recreation as well as other social-cultural values such as aesthetic value (enjoyment of scenery) and natural and cultural heritage (Estonian Ministry of Environment & SEI Tallinn, 2013). The effects of eutrophication on the provision of food are still not much analysed. Paulsen (2007) assessed the impact on the eelgrass beds at the Swedish Western Coast. He estimated the costs to EUR 100 million to 150 million (1 to 1.5 billion SEK) over a period of 55 years.

Turner et al (1999) estimated the value of the reduced supply of nutrients to the sea with 4.5 billion Euros. Stated preference studies for different countries show a willingness to pay (WTP) for the reduction of eutrophication. Ahtihainen et al (2014) conducted one of the rare studies which included all riparian countries and assessed the WTP of EUR 6 to 75 per person per year for achieving the targets of the Baltic Sea Action Plan (BSAP). For all Baltic countries this would mean an amount of EUR 3,600 million per year. But a broad variety of results are shown within the studies. For the same reduction, Gren et al (1997) estimated EUR 385 per person per year for Sweden and Markowska and Zylicz (1999) estimated a value of EUR 61 to 150 per Person per year for Poland and Lithuania. Atkins and Burdon (2006) valued the willingness to pay for a reduction of eutrophication in Denmark with EUR 120 per person per year.

These findings are supported by Hasselström (2008) who carried out an interview study including each of the nine Baltic Sea countries. He concluded that blue green algae blooms caused by eutrophication were currently considered to be the most important nuisance reducing aesthetic and recreational values in beach and coastal areas across the Baltic Sea area. However, Hasselström (2008) found that the presence of the algal blooms did not appear to have any significant impact on bookings or profits in the tourist industries presently. But he also mentions that there are strong indications that an increased frequency or duration of the blooms may have serious impacts on beach tourism sector.

Ahtiainen et al. (2014) estimated the additional value for a Baltic Sea with a good eutrophication status and therefore reduced input of nutrients in the different Baltic Countries. The estimates are based on interviews in all nine Baltic States. Ahtiainen et al. estimated a WTP of EUR 3.6 billion per year for all States; WTP for each county see in Table 10.

Table 10: Annual loss of benefits by eutrophication

Country	EUR million per year (prices 2011)	EUR per person[8] (prices 2011)
Germany	1706.1	23-27
Russia	693.0	8-9
Sweden	572.7	60-92
Poland	299.2	12-13
Denmark	125.6	28-36
Finland	151.1	40-43
Estonia	23.7	20-29
Lithuania	22.1	8-9
Latvia	9.2	5-6
Total	**3603**	

Source: Ahtiainen et al, 2014.

Table 11 shows a summary of changes to environment by shipping in the Baltic Sea. The relative importance of shipping on the change of environment is defined as the proportion of the change related to shipping compared to other sources, e.g. for air quality a lot of other sources influencing air quality beside of shipping exist,

[8] The ranges show the 95% confidence interval.

therefore it is estimated as low (+). + = low share compared to other sources, ++ = medium share compared to other sources, +++ = high share compared to other sources. The relative importance is based on expert judgements by the authors.

Table 11: Summary of state of change to environment by shipping in the Baltic Sea

State	Relative importance of shipping	Associated change to the environment (examples)	Link to human well being
Air quality	+	Hazardous particles causing lung cancer and cardiopulmonary diseases	Human health
Acidification	++	Increased Ph levels in marine waters	Tourism and recreation Commercial fishing Recreational fishing
Fish stock	+	Decreasing spawning grounds or juvenile fish	Commercial fishing Recreational fishing Genetic resources
Food Web	+	Toxins or contaminants entering the food system through fish	Human health
Invasive alien species	+++	Reduced genetic gene pools and cause extinction of endemic species and damage to habitats	Commercial fishing Recreational fishing Other socio-cultural values Genetic resources
Water quality	+	Contaminants and toxins entering the water (e.g. copper)	Commercial fishing Recreational fishing Tourism and recreation Other socio-cultural services Human health
Waste and litter	+	Influences beach aesthetics and causes damage to fishing activities	Commercial fishing Recreational fishing Tourism and recreation Human health Other socio-cultural values
Noise levels	+++	Leads to numerous (e.g. perceptual, behavioural) impacts on fish and mammals	Commercial fishing Recreational fishing Tourism and recreation
Oil spills	+++	Effects fish and mammals, as well as genetic resources and leads to aesthetic damages	Commercial fishing Recreational fishing Tourism and recreation Human health Climate change mitigation Coastal protection Other socio-cultural services Genetic resources
Loss of biodiversity	+	Pollution (incl. emissions) from shipping impacts biodiversity.	Commercial fishing Recreational fishing

State	Relative importance of shipping	Associated change to the environment (examples)	Link to human well being
			Tourism and recreation Other socio-cultural values Genetic resources Coastal protection Climate change mitigation
Coastal vegetation	++	Effects habitats providing nurseries, refugees and foraging areas for fish as well as reduces coastal erosion, improves water quality and absorbs the kinetic energy of currents and waves.	Coastal protection Commercial fishing Recreational fishing Tourism and recreation Climate change mitigation
Eutrophication	++	Green algal blooms create an aesthetic nuisance and impact the provision of food	Tourism and recreation Commercial fishing Recreational fishing Other socio-cultural values

3.2.3 Impacts on human well being

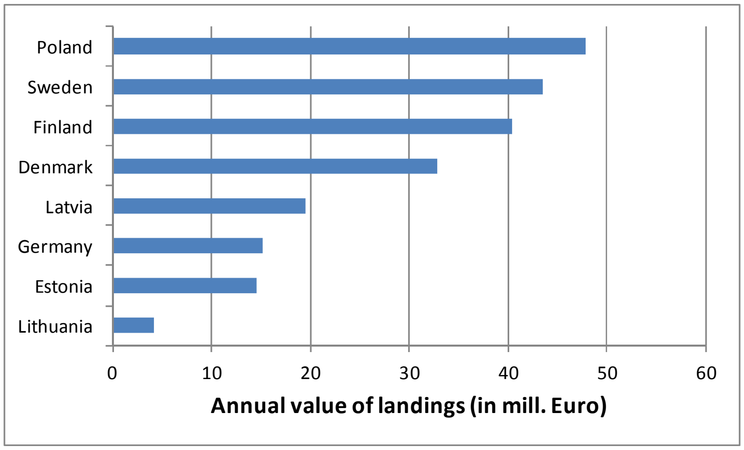
The following aims to explain the impacts by shipping on human well being linked to human health and the current beneficiaries and benefits provided by the Baltic Sea ecosystem services.

Commercial fishing

Fish for consumption is one of the dominant provisioning ecosystem services of the Baltic Sea (Garpe, 2008). For commercial fishing the most relevant species are cod, sprat and herring. Fishing industries and the respective trading and processing industries are directly benefitting from this service. But the economic importance is relatively limited when compared to other industries.

In 2014, the Baltic Sea commercial fishing fleet (excluding Russia) generated approximately 571 thousand tonnes and EUR 218 million in weight and value of landings, respectively. The countries with the highest landed weight were Finland (148 thousand tonnes), Poland (119 thousand tonnes) and Sweden (101 thousand tonnes). In terms of value, the countries generating the most were Poland (EUR 48 million), Sweden (EUR 43.5 million), Finland (EUR 40 million) and Denmark (EUR 33 million) (see below, Figure 22). Collectively these countries are accounted for around 76% of the total value of landings in the Baltic Sea in 2014 (STECF, 2016). In regard to employment in the Baltic Sea fishing fleet, there were 5,076 people employed (Full Time Equivalents) with 3,195 in the small scale fleet and 1,881 in the large scale fleet (STECF, 2016).

Figure 22: Annual value of landings in Baltic Sea in 2014



Source: STECF, 2016.

In the fish processing industry in Sweden 1,767 people are employed and an added value of EUR 144 million is estimated. Latvia, Lithuania and Finland show an added value by the processing industry of EUR 50 - 84 million for 2014 (Kettunen et al, 2013, Eurostat 2017a). Therefore, it is relatively small scale, but the processing industry creates jobs in less densely populated areas. They are as well maintaining cultural heritages in coastal communities and have therefore local importance.

Additionally, cultivated production of animals and plants (CICES, 2013) are increasingly relevant for nations which share a coastline with the Baltic Sea. In 2014 the turnover for fish aquaculture in marine areas were EUR 79 million, divided mainly between Denmark (EUR 57 million) and Finland (EUR 20.2 million) (STECF, 2016). The most popular species for cultivated fish are Salmonid fish (e.g. salmon and rain-bow trout), in a limited manner a variety of other species are cultivated. The value of Baltic salmon catches is estimated by Kulmala et al (2012). The commercial salmon landings in Denmark, Finland, Poland and Sweden were estimated with an economic value of EUR 0.9-3.6 million per year for 2009-2015. Beside the importance for commercial fishing estimates suggest that the recreational fishing of salmon and the cultural importance is even greater than the economic value. Besides fish also other marine organisms as shellfish (provisioning services) are influenced by shipping for examples catches of crabs and mussels. Shellfish aquaculture has a lower relevance than finfish aqcuaculture in the Baltic Sea, e.g. the turnover of blue mussels in Denmark was EUR 1.3 million per year (HELCOM, 2017c).

Recreational fishing

In Sweden, the number of recreational fishermen is estimated to be one million (Swedish EPA 2010) and over 6 million for the Nordic Countries (European Anglers Association, 2012 cited in Kettunen, 2013). It is estimated that 30 to 50 % of the population in Sweden and Finland are engaged with fishing at least once throughout a year. In Finland about 1.100 enterprises related to fishing tourism are counted (Kettunen et al., 2012). This sector contributes to local tackle shops, tackle manufacturers, bait suppliers, marine operators, and specialised angling media, angling tourism and other related business (Spahn, 2016). Recreational fishing is also relevant for regarding traditions and cultural heritage

The value of recreational fishing was prepared based on several studies on anglers' willingness to pay for improved quality of recreational fishing and for preserving wild salmon stock, ranging from EUR 8 to 19 per fishing day. Recreation was valued as well by Toivonen et al. (2004), they estimated the value of recreational fishing with EUR 57 to 88 per person per year for Denmark, Sweden and Finland.

Concerning recreational fishing the decrease of cod stock has been mentioned. Therefore interviewees suggested reducing and stopping industrial trawling for cod as there is a massive existence value in not extinguishing the stocks. Furthermore, the economic value of recreational fishing is much higher than industrial fishery. Also small scale coastal commercial fishery and their activities in fishery village are crucial for tourism in the area (Hasselström, 2008).

Genetic resources

Genetic resources are valuable and include unique genes, genotypes and populations (Johannesson & André 2006). The species in the Baltic Sea are estimated with more than six thousand. The loss of genetic resources and loss of biodiversity is seen as problematic for the Baltic Sea. The majority of the original wild Baltic salmon population is extinct. The genetic variation of the species is already lost due to heavily reduced population size (Bailey, 2011, Ojaveer et al., 2010, Ahtiainen & Öhman, 2013). However, this gene pool is potentially crucial to unlock the fish genomes, in order to breed fish in aquaculture farms more efficiently, for example by requiring less animal protein (Garpe, K., 2008). Additionally, a bigger gene pool potentially leads to a higher resilience of the species when facing those rapid changes that are currently occurring, such as climate change or acidification. The genetic resources also provide potential future prospects for the growing blue bioeconomy, namely the blue biotech sector. Today, for example the use of algae from the Baltic Sea as medication against cancer (Piker et al., 2010) is researched.

Climate change mitigation

The interlinkages between climate change and marine spaces are becoming increasingly recognised. This means that the marine spaces such as the Baltic Sea play a critical role in mitigating climate change, in particular through carbon sequestration – also known as blue carbon. Seagrass meadows play a critical role in the sequestration of carbon because of their capacity to absorb and store carbon, both living and dead as well as in sediment. The coasts of Scandinavia and the Baltic Sea are important areas for the distribution of eelgrass, which extend from the Norwegian coast to the archipelago areas of Finland. It is estimated that the region supports over 6,000 individual meadows covering over 15000 to 20000 km^2, or four times more than the combined area of Western Europe (Rohr et al., 2016). As a result, the area plays a significant role in the mitigation of climate change. However, seagrasses are being lost at significant rates and it is estimated that about 29% of global seagrass has disappeared since 1879 (Rohr et al, 2016). It is estimated that the present economic value of carbon storage and sequestration capacity of Baltic Sea eelgrass meadows is between 1.7 and 12 % out of the global seagrass blue carbon value (Rohr et al., 2016). The further loss of seagrasses could play a devastating role in the Baltic Sea's capacity to aid in climate change mitigation.

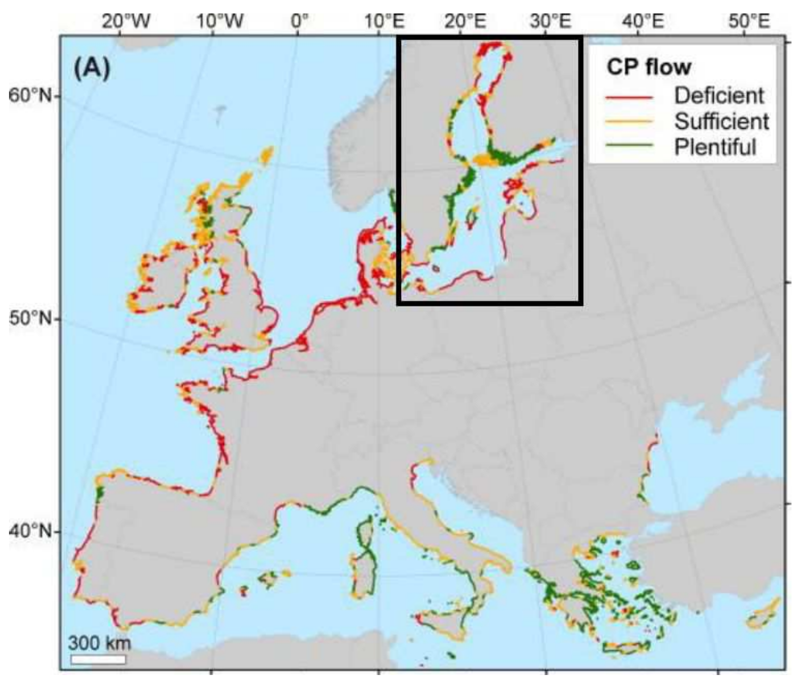
Coastal security protection

The existing evidence about the role of Baltic Sea marine ecosystems supporting coastal protection is rather limited. Similar to the role of climate mitigation, the capacity of the Baltic Sea to provide coastal security is linked to health of habitats such as seagrass meadows and coastal salt marshes. The role of natural habitats to support coastal protection in particular from coastal storms and extreme weather events is particularly valuable along the Baltic Sea coast (IEEP, 2017). Nevertheless, estimations on the monetary value of coastal protection by seagrass meadows and coastal salt marshes are very limited.

However, Liquete et al. provided data on the 'flow of coastal protection as ecosystem service' (Liquete et al., 2013). Coastal protection service flow is estimated as combination of coastal protection capacity and natural exposure (Liquete et al., 2013). While the natural exposure is mainly determined by wave regime, storm surge and partially by relative sea level change and tidal amplitudes, coastal protection capacity is mainly driven by geomorphology, the presence or certain habitats whose physical structure may disrupt the water movement or adapt their form to it (Liquete et al., 2013). This coastal protection capacity is relatively low along the shores of Denmark and Germany (Liquete et al., 2013).

As Figure 23 shows, the coastal protection service flow is rather deficient for human needs in the Southern Baltic and northern Bothnian Bay (Liquete et al., 2013). The deficient coastal protection service flow in the northern Bothnian Bay can also be explained by the very high natural exposure values. With regards to natural exposure, the results of the coastal protection service flow in the south-west Baltic Sea are controlled by low wave regime values (Liquete et al., 2013).

Figure 23: Coastal protection service flow (CP flow) in Europe (Baltic Sea marked)



Source: Liquete et al., 2013.

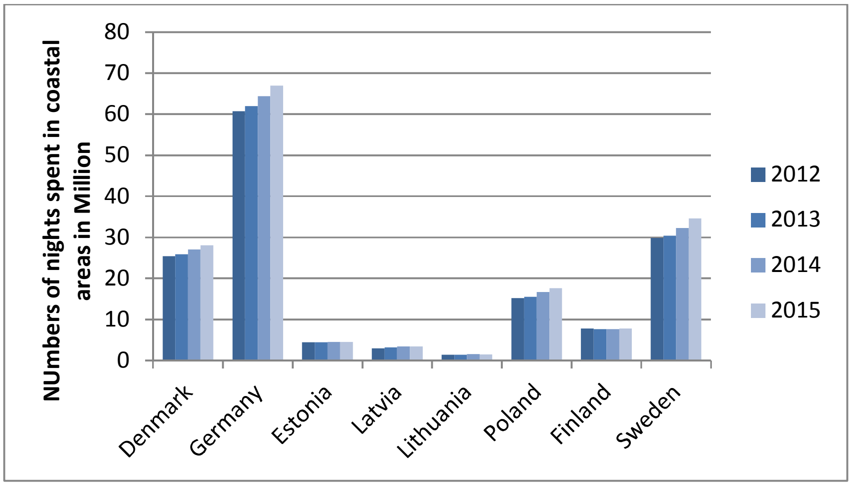
Tourism and recreation

For the people living in the Baltic countries the Baltic Sea is an important recreation area. Over 80 % of people in the coastal regions have spent leisure time at the Baltic Sea area (except Russia). The majority of the population of Denmark, Estonia, Finland, Latvia and Sweden are visiting the Baltic Sea during a year. The most popular activities are swimming and spending time at the beach (Swedish EPA, 2009, 2010).

In 2012 the countries of the Baltic Sea region accounted for 73 million international arrivals and a total number of 570 million overnights (Confederation of Danish Industry, 2014). These numbers equal to 7 percent of the world's tourism measured by international arrivals and 13 % of the tourism in Europe in the year 2012 (Confederation of Danish Industry, 2014). Since then, the number of nights spent in the coastal area increased during the last years slightly (Eurostat 2017b).

For Estonia (79 %), Latvia (84 %) and Denmark (91 %) coastal tourism represents by far the main share of accommodations (for 2013) (Eurostat 2017b, 2017c).

Figure 24: Number of nights spent in coastal areas



Source: Eurostat (2017b), Data for Denmark and Germany includes stays at the Baltic Sea and North Sea coast.

Although there is a wide range of different estimation about the revenues and employment effects of the tourism sector in the Baltic Sea, there is no doubt, that its role is relevant – especially for the coastal countries of the Baltic States. Despite the economic decline in early 2010, coastal tourism in the Baltic Sea region has risen 5.3 % annually 2009 to 2012, when 2012 42 billion EUR was created in the coastal regions of the Baltic Sea but of course not all activities in the area are connected to the sea (Holfve et al., 2013). The biggest increment was observed in Sweden, which had an annual growth of 6.9 % in that time (Holfve et al., 2013).

Most of the tourists that led to that growth rate, by the Baltic Sea Coastal region stem from the Baltic Sea region itself. In Mecklenburg–Vorpommern, a German federal state at the Baltic coast, in 2014 the share of foreign visitors was 5.1% (Statistisches Amt Mecklenburg-Vorpommern, 2015). Thus it is mainly the domestic tourism, which led the German overall employment in coastal tourism grew by 11 % between 2008 and 2010 (Beyer et al., 2017).

Czajkowski et al. (2015) estimated the annual value of marine and coastal recreation in the Baltic Sea with about EUR 14.8 billion per year. Furthermore, they estimated the annual recreational visits to the Baltic Sea per person of population. The value was estimated along the travel costs and the number of recreational visits which is split up by the countries with the highest value for Germany, Sweden and Poland.

Table 12: Annual value of marine and coastal recreation in the Baltic Sea

Country	Annual value of Baltic Sea recreation visits (EUR million)	Average number of annual recreational visits to the Baltic Sea per person
Denmark	720	6.0
Estonia	150	1.8
Finland	1040	4.0
Germany	5140	1.2
Latvia	110	2.6
Lithuania	190	1.7
Poland	2070	1.1
Russia	940	0.5
Sweden	4430	6.4
Total	**14790**	

Source: Czajkowski et al, 2015 cited according to HELCOM, 2017c.

Marine tourism and recreation is affected especially by eutrophication, oil spills, acidification, change of coastal vegetation and non-indigenous species in several ways. The effects of eutrophication differ depending on the touristic activities. It is expected that boating, vacation homes, commercial establishments and activities corresponding with one-day trips to the sea show the highest effects by reduced demand for recreational activities caused by environmental degradation. Valuation studies on ecosystem services are rarely linked to individual recreational activities (Estonian Ministry of Environment & SEI Tallinn 2013).

Hasselström (2008) highlights that for Sweden, Finland, Denmark and Germany there is a higher dependency between environmental state and tourism than for the other Baltic States. Beach tourism and recreational fishing seem to be the tourism sectors most sensitive to environmental problems and changes on marine ecosystems. Beside the eutrophication problem, the interviewees mention increased oil spill accidents as a frightening scenario. A major oil spill accident seems to have a huge impact on tourism in the affected area.

Other socio-cultural services

Other socio-cultural services include services such as aesthetic value, cultural and natural heritage, research and education. Cultural ecosystem services related to Baltic Sea food webs were studies by Lewis et al. (2013). They implemented a choice experiment in Poland in 2012 and elicited willingness to pay for four ecological features: algal bloom intensity and timing, local species visibility, regional species population and local fisheries catch consistency and profitability. The findings increase the information on the value of cultural ecosystem services provided by the Baltic Sea in Poland.

There is also a value of the Baltic Sea for education and research. There are a large number of educational institutions and more than 5.100 scientific publications listed in the "ISI Web of Science" database, with the word "Baltic Sea" in the title (Ahtiainen & Öhman, 2013, data updated in 2017). Underwater cultural heritage may be estimated through the number of shipwrecks which are historically import and also because they provide popular locations for visitors and in particular divers. It is estimated that there are about 115 underwater shipwrecks in the Baltic Sea (in Danish, Finnish, German, Russian, and Swedish waters) (Nord Stream, 2013).

Human health

The health impacts of SO_X, NO_X and PM from shipping in the North and Baltic Sea is estimated for Denmark and whole Europe in 2011. The Danish Ecocouncil (2011) estimates 4,000 years of lost living for Denmark and 150,000 lost years of living for whole Europe. Smaller airborne particles get into the lungs and pass through tissues and enter the blood. They can then trigger inflammations which eventually cause heart and lung failures. Certain cases of lung cancer and heart failures can be linked to air emissions by shipping. 400,000 illness days are estimated for Denmark and 13.4 million days for whole Europe caused by the three types of emissions in the Northern Sea and Baltic Sea. Finally the Danish Ecocouncil (2011) concludes that 75-80 % of the total health damages in Denmark from shipping in the North Sea and the Baltic Sea are caused by air pollution from shipping.

The total contribution from international shipping in the Northern Hemisphere was estimated with 7 % of the total health related effects in Europe in the year 2000. The total external cost related to health issues caused by shipping are estimated with EUR 56 billion per year for the Northern Hemisphere (Brandt et al, 2013). The following table shows a summary on the impacts on human well being from shipping, including the relative importance of the different pressures, costs of degradation and economic importance.

Summary of effects on human well being

Table 13: Effects on human well being

Human well being	Ecosystem services	Link to state	Costs of degradation	Economic importance
Commercial fishing	Cod, sprat, herring, salmon and sea-food	Fish stocks Food web Water quality Eutrophication Oil spills Loss of biodiversity	Costs generated by shipping are potentially low compared to other factors such as overfishing.	The economic contribution of fishing to GDP is limited on national level, but can have a substantial local importance, and is also linked to tourism and visitors.
Recreational fishing	Cod, sprat, herring, salmon and sea-food)	Fish stocks Food web Water quality Eutrophication Oil spills Loss of biodiversity	Costs generated by shipping are potentially significant – and especially relevant due to eutrophication and oil spills.	Economic importance of recreational fishing is substantial, especially for local communi-ties.
Genetic resources	Genetic variation of species	Loss of biodiversity Water quality Invasive Alien Spe-cies	Costs generated by shipping are potentially significant as genetic resources can be in-fluenced especially by invasive species.	The economic importance is linked to ma-rine materials, fishing, recreation and cul-tural values.
Climate change mitigation	Capacity of sea to absorb CO_2 (i.e. seagrass meadows)	Coastal vegetation Loss of biodiversity	Costs generated by shipping are potentially low, as threats i.e. to seagrass meadows are multiple.	The economic importance is significant globally.
Coastal protection	Capacity of sea to protect coastline, sediments, avoid erosion (i.e. sea-grass meadows)	Coastal vegetation Loss of biodiversity	Costs generated by shipping are potentially low, as threats i.e. to seagrass meadows are multiple.	The economic importance is significant.
Tourism and rec-reation	Swimming, beach activities	Eutrophication Water quality Oil spills	Costs generated by shipping are potentially significant – and especially relevant due to eutrophication, oil spills, and low water	Economic importance of tourism is substan-tial for local communities.

Human well being	Ecosystem services	Link to state	Costs of degradation	Economic importance
			quality.	
Other socio-cultural services	Heritage, inspiration, local and regional species	Eutrophication Oil spills Water quality	Costs generated by shipping are potentially significant.	The economic importance locally is expected to be high, but difficult to estimate.
Human health	Clean air	Air quality	Costs generated by shipping are potentially limited as air quality is influenced by a variety of drivers. However, in selected local settings the pressure from shipping could be significant. Compared to other categories of human well being the absolute costs are still significant.	Costs of human health impacts by air quality are high.

Future scenarios

In an effort to understand potential future changes to ecosystem services and effects on human well being, cumulative scenarios were developed in the BONUS SHEBA project (as described in section 1.2). The three scenarios were chosen to show future variations to the shipping sector based on various policy and or technology initiatives. *SSP1* is named 'Sustainability' scenario and thus includes a sustainable development with high concern for the environment and good technology development with focus on renewables and efficiency. *SSP2* is the 'Middle of the Road' scenario where recent trends continue. This means a reduction in resource and energy use and slowly decreasing use of fossil fuel. For shipping, this scenario is here interpreted as the same as the BAU scenario. *SSP3* is the 'Fragmentation' scenario where there is development in some world regions and poverty in others leading to continued fossil fuel dependency and failure to meet environmental goals.

The above sections sought to link the main pressures from the shipping sector, to changes in state of the environment and human health, to impacts on human well being. Table 14 below depicts the broad variations to human well being in these scenarios compared to BAU, understood as costs, and based on expected changes to pressures stemming from the shipping sector. For each of the three scenarios potential costs to human well being are indicated based on relevant pressures. The symbols mean: ↗ increasing costs of degradation (i.e. losses) for human well being are expected in the scenario due to to increasing pressure; ↘ decreasing costs (i.e. gains) for human well being are expected in the scenario due to decreasing pressure; and, → no major changes for human well being compared to the status quo are expected due to stagnating pressure. The symbols should be considered in relation to BAU. For example, this means that there may be a decrease to human well being compared to BAU while overall or in absolute terms there may be an increase to those costs. Arrows marked green indicate a positive change (i.e. reduction in costs to human well being) while red indicates a negative change (i.e. increase in costs to human well being) compared to BAU – in terms of costs to human well being. Changes for *SSP1* and *SSP3* are described in a one step change from the arrow in the *SSP2* (BAU scenario), e.g. Costs of degradation for CO_2 emissions are stagnating in the *SSP2* scenario (→), in the *SSP1* the sustainability scenario the Costs caused by CO_2 emission are lower – this is transferred to a downwards arrow (↘).

A number of regulations are included in the BAU scenario developed within BONUS-SHEBA (Fridell et al., 2016) and will potentially influence the costs of well being affected by shipping and are therefore taken into account (see section 1.2). In regard to SO_X, the BAU assumes that a fraction of scrubbers (open and closed) as well as a mixture of low sulphur fuels will limit (0.1%) from 2015, and global limit (0.5 %) from 2020 leading to minor reductions in emissions (Fridell et al, 2016). In regard to NO_X emissions, the NO_X regulation of MARPOL is constructed with three Tiers, and each Tier requires further reductions of emissions compared to the previous. All NO_X regulations in MARPOL primarily apply to new built ships only. The regulation is constructed so that only new vessels will need to comply with the Tier III emission limits. No actions need to be taken to reduce emissions from ships constructed before the year 2021. As a consequence the emissions will not be reduced at an instant. Instead, total emission levels will be reduced only slowly and could even increase if the ship traffic increases. Tier II levels accomplish approximately 15 % to 20 % reductions in NO_X emissions compared to a Tier I engine. These reductions can often be accomplished by adjustments of combustion parameters on existing engine models. Fulfilling requirements of Tier III yields reductions of NO_X emissions by approximately 80 % compared to the Tier I levels (Fridell et al., 2016). Greenhouse gas emissions may show slight decreases as vessels will be designed to meet stricter EEDI rules for better fuel efficiency. At the same time, it is expected that ballast water will continue to be transported at current trends. Although the Ballast Water Convention will come into force there will be significant lag before all ships have updated for the regulation. Similarly, the use of LNG as well as hull paints is expected to follow similar trends (Fridell et al., 2016).

Table 14: Costs of degradation for future scenarios 2030/2040 compared to BAU

			Costs to human well being							
Scenario	**Pressure**	**Relative importance of shipping**	**Commer-cial fishing**	**Recrea-tional fish-ing**	**Genetic resources**	**Climate change mitigation**	**Coastal protection**	**Tourism and recrea-tion**	**Other socio - cultural values**	**Human health**
SSP2 Middle of the road (Businesn As Usual)	CO_2	+	→	→	→	→	→	→	→	→
	NO_X	++	↘	↘				↘	↘	↘
	SO_X	+	→	→				→	→	→
	PM	++								→
	Non-indigenous species	+++	↘	↘	↘			↘	↘	↘
	Contaminants to water	+	→	→	→	→	→	→	→	→
	Oil spills	+++	↘	↘	↘	↘	↘	↘	↘	↘
	Underwater noise	++	↗	↗				↗	↗	
	Physical impacts	+++	↗	↗	↗	↗	↗			
SSP1 Sustainability	CO_2	+	↘	↘	↘	↘	↘	↘	↘	↘
	NO_X	++	↘	↘				↘	↘	↘
	SO_X	+	↘	↘				↘	↘	↘
	PM	++								↘
	Non-indigenous species	+++	↘	↘	↘			↘	↘	↘
	Contaminants to water	+	↘	↘	↘	↘	↘	↘	↘	↘
	Oil spills	+++	↘	↘	↘	↘	↘	↘	↘	↘
	Underwater noise	++	→	→				→	→	
	Physical impacts	+++	→	→	→	→	→			
SSP3 Fragmentation	CO_2	+	↗	↗	↗	↗	↗	↗	↗	↗
	NO_X	++	→	→				→	→	→
	SO_X	+	↗	↗				↗	↗	↗
	PM	++								↗
	Non-indigenous species	+++	→	→	→			→	→	→
	Contaminants to water	+	↗	↗	↗	↗	↗	↗	↗	↗
	Oil spills	+++	→	→	→	→	→	→	→	→
	Underwater noise	++	↗	↗				↗	↗	
	Physical impacts	+++	↗	↗	↗	↗	↗			

Slow steaming scenario

The *slow steaming scenario* of BONUS-SHEBA assumes a general reduction in speed (10 % decrease) in 2030 and 2040 compared to 2014. It is expected to lead to changes in emissions to air and water as well as noise. However, if slow steaming continues in large scale and there is an increase in trade, more vessels will be needed to achieve the same capacity levels. According to modelling results, there will be a reduction in fuel consumption and air emissions but an increase in water emissions and noise emissions due to the larger number of ships (Fridell et al. 2016). The changes to human well being compared to BAU due to the implementation of slow steaming in the Baltic Sea are reflected in the Table 15.

Modal shift from land to sea

A *modal shift from land to sea scenario* was also investigated to understand the changes in emissions to air and water as well as underwater noise brought on by transferring carrying capacity from land to water. Compared to Business As Usual, the results show more RoRo and container traffic from the North Sea to Poland, Russia, Estonia, Lithuania and Latvia. According to the modelling, there will be an overall increase of the impacts from shipping; while there will be a decrease of impacts from land-based transport (Fridell et al. 2016). The tradeoffs between land and sea based traffic are not included in this assessment. Only the impacts from shipping are included here. The changes to human well being compared to BAU due to a modal shift from land to sea in the Baltic Sea are reflected in the Table 15.

NECA/NoNECA 2021

As the *BAU scenario* includes the introduction of a NECA in the Baltic and North Sea in 2021, a *NoNECA 2021 scenario* was considered as well. The scenario is built on the assumption that the NECA is not introduced and the Tier III requirement for NO_X emissions for new ships will not begin in 2021. As a result, it is expected that there will be an increase in emissions of NO_X compared to the *BAU scenario* which includes the implementation of the NECA (Fridell et al. 2015). The changes to human well being compared to BAU due to the *NoNECA 2021 scenario* in the Baltic Sea are reflected in the Table 15.

Zero emissions to water

In the *zero emissions to water scenario*, the changes to the impact on the Baltic Sea caused by various regulations limiting emissions to water from shipping were investigated. In particular, the scenario tested potential changes due to prohibiting black water emissions, the discharge of grey water and or bilge water, no open loop scrubbers, having the Ballast Water Management Convention in place, and the use of only biocide-free paint. As a result, there can be expected lower emissions of nutrients as well as reduced transport of invasive alien species compared to Business As Usual (Fridell et al. 2016). The changes to human well being compared to BAU due to the *zero-emissions to water scenario* in the Baltic Sea are reflected in the Table 15.

LNG

An *LNG scenario* to investigate changes in emissions to air and water from an increased use of LNG in the Baltic Sea and North Sea up to 2040 was developed. The scenario assumes new RoRo and RoPax ships use LNG from 2016 onward, while for other ship types, it is expected that half of the fuel used in new built ships with a gross tonnage below 30,000 are LNG fuelled. No retrofit installations are assumed. Compared to Business As Usual, the results of the scenario suggest a reduction in emissions of PM, SO_2 and NO_X and a slight decrease of CO_2 as old vessels are replaced by new ones, while there is an increase in CH_4 emissions (Fridell et al. 2016). The changes to human well being compared to BAU due to the LNG scenario in the Baltic Sea are reflected in the Table 15.

Port measures

A *port measures scenario* was also developed to investigate the changes in impact on air and water quality from measures in ports, mainly shore-side electricity (onshore power supply, OPS) and other measures to replace the ship auxiliary engine use while at berth. Compared to Business As Usual, it is expected result in overall lower fuel consumption and therefore lower emissions to air and less noise (Fridell et al, 2016). The changes to human well being compared to BAU due to the port measures scenario in the Baltic Sea are reflected in the Table 15.

The following table describes the assessment of Costs of degradation for the different single scenarios. It is established in comparison to the BAU scenario (included as the *SSP2* cumulative scenario).

Summary of costs to human well being in single scenarios

Table 15: Costs to human well being in single scenarios

			Costs to human well being							
Scenario	**Pressure**	**Relative importance of shipping**	**Commercial fishing**	**Recreational fishing**	**Genetic resources**	**Climate change mitigation**	**Coastal protection**	**Tourism and recreation**	**Other socio - cultural values**	**Human health**
Business As Usual (BAU)	CO2	+	→	→	→	→	→	→	→	→
	NOx	++	↘	↘				↘	↘	↘
	SOx	+	→	→				→	→	→
	PM	++								→
	Non-indigenous species	+++	↘	↘	↘			↘	↘	↘
	Contaminants to water	+	→	→	→	→	→	→	→	→
	Oil spills	+++	↘	↘	↘	↘	↘	↘	↘	↘
	Underwater noise	++	↗	↗				↗	↗	
	Physical impacts	+++	↗	↗	↗	↗	↗			
Slow steaming	CO2	+	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)
	NOx	++	↘	↘				↘	↘	↘
	SOx	+	↘ (green)	↘ (green)				↘ (green)	↘ (green)	↘ (green)
	PM	++								↘ (green)
	Non-indigenous species	+++	→ (red)	→ (red)	→ (red)			→ (red)	→ (red)	→ (red)
	Contaminants to water	+	→	→	→	→	→	→	→	→
	Oil spills	+++	↘	↘	↘	↘	↘	↘	↘	↘
	Underwater noise	++	↗	↗				↗	↗	
	Physical impacts	+++	→ (green)	→ (green)	→ (green)	→ (green)	→ (green)			

			Costs to human well being							
Scenario	**Pressure**	**Relative importance of shipping**	**Commercial fishing**	**Recreational fishing**	**Genetic resources**	**Climate change mitigation**	**Coastal protection**	**Tourism and recreation**	**Other socio - cultural values**	**Human health**
Modal shift from land to sea	CO2	+	↗ (red)	↗ (red)	↗ (red)	↗ (red)	↗ (red)	↗ (red)	↗ (red)	↗ (red)
	NOx	++	→ (red)	→ (red)				→ (red)	→ (red)	→ (red)
	SOx	+	↗ (red)	↗ (red)				↗ (red)	↗ (red)	↗ (red)
	PM	++								↗ (red)
	Non-indigenous species	+++	→ (red)	→ (red)	→ (red)			→ (red)	→ (red)	→ (red)
	Contaminants to water	+	↗ (red)	↗ (red)	↗ (red)	↗ (red)	↗ (red)	↗ (red)	↗ (red)	↗ (red)
	Oil spills	+++	→ (red)	→ (red)	→ (red)	→ (red)	→ (red)	→ (red)	→ (red)	→ (red)
	Underwater noise	++	↗ (black)	↗ (black)				↗ (black)	↗ (black)	
	Physical impacts	+++	↗ (black)	↗ (black)	↗ (black)	↗ (black)	↗ (black)			
NoNECA 2021	CO2	+	→ (black)	→ (black)	→ (black)	→ (black)	→ (black)	→ (black)	→ (black)	→ (black)
	NOx	++	→ (red)	→ (red)				→ (red)	→ (red)	→ (red)
	SOx	+	→ (black)	→ (black)				→ (black)	→ (black)	→ (black)
	PM	++								→ (black)
	Non-indigenous species	+++	↘ (black)	↘ (black)	↘ (black)			↘ (black)	↘ (black)	↘ (black)
	Contaminants to water	+	→ (black)	→ (black)	→ (black)	→ (black)	→ (black)	→ (black)	→ (black)	→ (black)
	Oil spills	+++	↘ (black)	↘ (black)	↘ (black)	↘ (black)	↘ (black)	↘ (black)	↘ (black)	↘ (black)
	Underwater noise	++	↗ (black)	↗ (black)				↗ (black)	↗ (black)	
	Physical impacts	+++	↗ (black)	↗ (black)	↗ (black)	↗ (black)	↗ (black)			
Zero emissions to water	CO2	+	→ (black)	→ (black)	→ (black)	→ (black)	→ (black)	→ (black)	→ (black)	→ (black)
	NOx	++	↘ (black)	↘ (black)				↘ (black)	↘ (black)	↘ (black)
	SOx	+	→ (black)	→ (black)				→ (black)	→ (black)	→ (black)
	PM	++								
	Non-indigenous species	+++	↘ (black)	↘ (black)	↘ (black)			↘ (black)	↘ (black)	↘ (black)
	Contaminants to water	+	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)
	Oil spills	+++	↘ (black)	↘ (black)	↘ (black)	↘ (black)	↘ (black)	↘ (black)	↘ (black)	↘ (black)
	Underwater noise	++	↗ (black)	↗ (black)				↗ (black)	↗ (black)	
	Physical impacts	+++	↗ (black)	↗ (black)	↗ (black)	↗ (black)	↗ (black)			

			Costs to human well being							
Scenario	**Pressure**	**Relative importance of shipping**	**Commercial fishing**	**Recreational fishing**	**Genetic resources**	**Climate change mitigation**	**Coastal protection**	**Tourism and recreation**	**Other socio - cultural values**	**Human health**
LNG	CO2	+	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)
	NOx	++	↘	↘				↘	↘	↘
	SOx	+	↘ (green)	↘ (green)				↘ (green)	↘ (green)	↘ (green)
	PM	++								↘ (green)
	Non-indigenous species	+++	↘	↘	↘			↘	↘	↘
	Contaminants to water	+	→	→	→	→	→	→	→	→
	Oil spills	+++	↘	↘	↘	↘	↘	↘	↘	↘
	Underwater noise	++	↗	↗				↗	↗	
	Physical impacts	+++	↗	↗	↗	↗	↗			
Port measures	CO2	+	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)	↘ (green)
	NOx	++	↘	↘				↘	↘	↘
	SOx	+	↘ (green)	↘ (green)				↘ (green)	↘ (green)	↘ (green)
	PM	++								↘ (green)
	Non-indigenous species	+++	↘	↘	↘			↘	↘	↘
	Contaminants to water	+	→	→	→	→	→	→	→	→
	Oil spills	+++	↘	↘	↘	↘	↘	↘	↘	↘
	Underwater noise	++	↗	↗				↗	↗	
	Physical impacts	+++	↗	↗	↗	↗	↗			

3.2.4 Case Study: The impact of air emissions from ships on human health in the Baltic Sea region

The largest part of shipping activities are transportation of good, especially with RoRo and RoPax shipping; compared to passenger and cruise shipping. In ports, mooring is responsible for the largest part of the emissions while manoeuvring and arrival and departure play minor roles for the emissions from ships. This is because ships still need power for heating, cooling and electricity when they are at berth. Cruise ships are the type of ships with the highest demand for power in ports. Thus, ships emit large amounts of air pollutants, which can then be transported into coastal areas with dense population. Nitrogen dioxide (NO_2), ozone (O_3) and particulate matter (PM) are all regulated in the EU. However, even when the concentrations stay below the set limit values, negative health effects can be expected from the exposure to elevated NO_2, O_3 and PM levels. As a consequence, people living at the coast and in harbor cities are heavily affected by air pollutants emitted from ships.

For these reasons, this case study was selected to estimate the impact of shipping emissions on human health in the Baltic Sea area. This is done by using the CMAQ model to calculate the dispersion and chemical transformation of air pollutants from shipping. Maps of shipping emissions for several pollutants were calculated with the STEAM model. Emissions of air pollutants from other sources in the Baltic Sea area stem from the EMEP centre on emissions inventories and projections (CEIP).

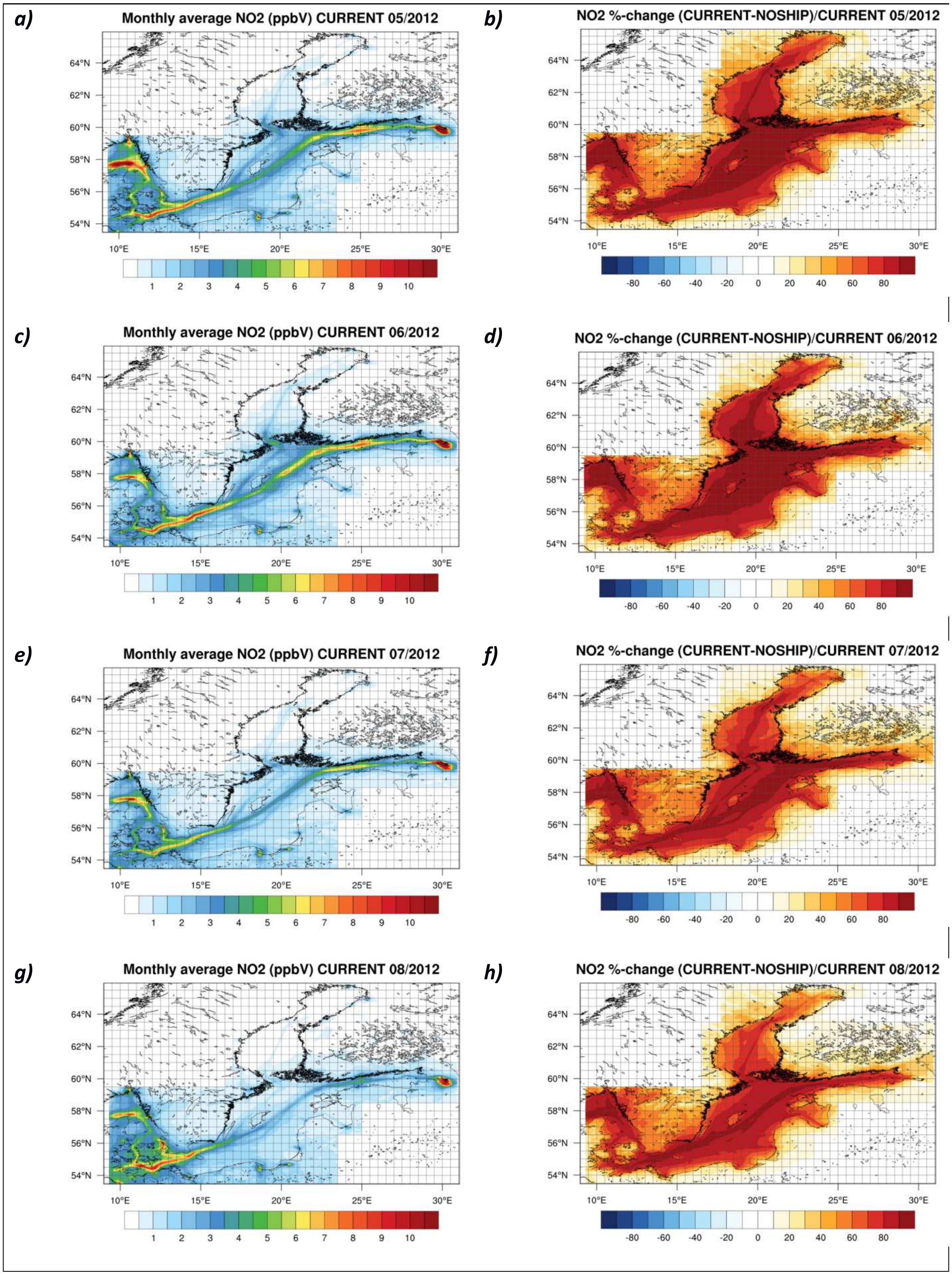
The area studied in this case study comprises the Baltic Sea and large parts of the riparian states. The total area is 6,811,000 km² and the total number of inhabitants is about 4.13 million people. Shipping emissions are expected to have a major impact on the concentrations of air pollutants in coastal areas. Shipping activities will likely increase in the future, however, exhaust gas cleaning technologies and energy efficiency increases will probably lead to reduced specific emissions (per ton of transported cargo).

The main pollutants responsible for human health effects are NO_2, O_3 and PM. They are well known to cause cardiovascular and respiratory diseases. The World Health Organization (WHO) recommends annual mean concentrations of 20 µg/m³ for PM10 and 40 µg/m³ for NO_2. Ozone plays a role if the concentration levels (daily maximum of the 8 hour mean) exceed 35 ppb (approx. 70 µg/m³) (Holland et al. 2005). EU limit values are annual mean concentrations of 40 µg/m³ for PM10 and for NO_2 and 120 µg/m³ for O_3. The latter shall not be exceeded on more than 25 days per year (WHO, 2013 a, b).

Shipping emissions are a relevant source for all of these pollutants. Nitrogen oxides and PM are directly emitted by ships. In addition, secondary particles will be formed from NO_x and SO_2 emissions in areas with significant NH_3 emissions. They stem mainly from agriculture. Large parts of the Baltic Sea coastal areas are used for agriculture. NO_x and VOC emissions play an important role for the formation of ozone. Therefore, part of the ozone concentrations can also be attributed to shipping. In many coastal areas shipping is the main contributor to the observed NO_x levels. Enhanced NOx emissions (emitted to ~95 % as NO) lead to reduced ozone concentrations close to the source and in regions where ratio between NOx and VOC concentrations is high. Shipping emissions will lead to reduced ozone concentrations close to the shipping lanes but to enhanced ozone concentrations further away.

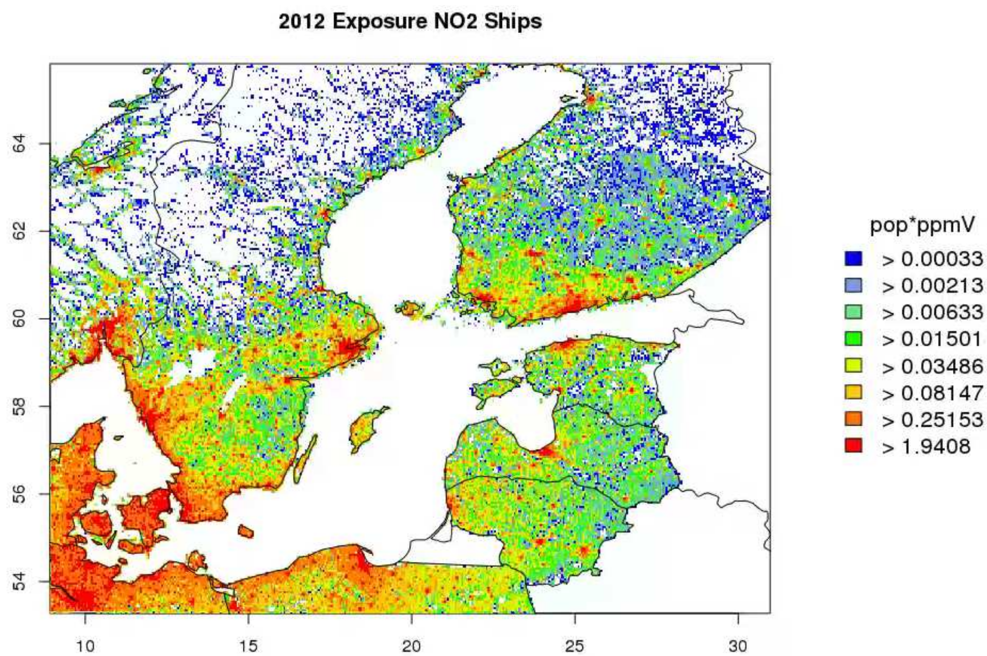
NO_2 concentrations over the Baltic Sea are dominated by shipping emissions (see Figure 25 for the summer months May to August). In many coastal regions, the contribution of shipping to the NO_2 concentrations at land reaches 40-80 %. On the other hand, the absolute concentrations are low (in the order of a few ppbV) and the contribution from ships quickly reaches values below 10 % further from the coast. All effects on air pollution are highly dependent on the meteorological conditions. They will vary largely from day to day and between seasons.

Figure 25: Monthly average NO_2 concentrations between May to August 2012 in the Baltic Sea area (left) and the contribution of shipping to these concentrations (right)



Enhanced levels of NO_2, $PM_{2.5}$ and ozone can lead to adversed health effects. Shipping contributes to this increased risk because of its contribution to the concentrations of the relevant substances. Figure 26 shows a map of the exposure of the population in the Baltic Sea area to NO_2 from shipping in 2012. Russia and Belarus are excluded because the population density data was not available for these countries. On the one hand the map reflects the areas with high population densities like the cities of Oslo, Stockholm, Helsinki and Tallinn. On the other hand, rural regions in Denmark and Sweden that have low population densities show high exposure due to high concentrations of air pollutants from shipping.

Figure 26: Population exposure to NO_2 from shipping for the year 2012. Russia is excluded because no population density data for Russia was available



The human exposure calculated for this sensitivity study was used as an input to the ALPHA Risk Pollution model (ARP) (Schucht et al., 2015) to calculate healt impacts and the associated monetary costs. The model approach of the health impact assessment follows recommendations of the REVIHAAP (Review of Health Aspects of Air Pollution) and HRAPIE (Health Response to Air Pollutants in Europe) studies of WHO, undertaken for revision of the European Commission's Thematic Strategy on Air Pollution (TSAP) (WHO, 2013a, b). By using age group specific population data projections from United Nations (2011) together with data on health impact incidence rates and data on concentration-response functions from WHO (2013a) the ARP model calculates health impacts from air pollution. Impacts on mortality are calculated as number of fatalities or reduction in life expectancy. A list of the health impacts reccomended by the HARPIE study is given in Table 16. The impacts in grey fields are not used in the TSAP methodology as the state of the knowledge is not mature to be included in the assessment and of a risk of doublecounting of impacts from NO2 and ozone with those from PM. These impacts were included for completeness as a sensitivity study.

Table 16. List of health impacts – HRAPIE recommendations. Functions in the grey fields have not been applied in the TSAP methodology and were calculated as sensitivity study (from Holland et al., 2015).

Impact / population group	Rating	Population	Exposure metric
All cause mortality from acute exposure	A*/A	All ages	O3, SOMO35 (A*)
Respiratory Hospital Admissions	A*/A	Over 65 years	O3, SOMO35 (A*)
Cardiovascular hospital admissions	A*/A	Over 65 years	O3, SOMO35 (A*)
Minor Restricted Activity Days (MRADs)	B*/B	All ages	O3, SOMO35 (B*)
All cause mortality from chronic exposure	B	Over 30 years	O3, SOMO35, summer months
All cause mortality from chronic exposure as life years lost or premature deaths	A*	Over 30 years	PM2.5, annual average
Infant Mortality	B*	1 month to 1 year	PM2.5, annual average
Chronic bronchitis in adults	B*	Over 27 years	PM2.5, annual average
Bronchitis in children	B*	6 – 12 years	PM2.5, annual average
Respiratory Hospital Admissions	A*	All ages	PM2.5, annual average
Cardiovascular Hospital Admissions	A*	All ages	PM2.5, annual average
Restricted Activity Days (RADs)	B*	All	PM2.5, annual average
Asthma symptoms in asthmatic children	B*	5 to 19 years	PM2.5, annual average
Lost working days	B*	15 to 64 years	PM2.5, annual average
All cause mortality from chronic exposure	B*	Over 30 years	NO2 annual mean >20ug.m-3
Bronchitis in children	B*	5 – 14 years	NO2 annual mean
Respiratory hospital admissions	A*	All ages	NO2 annual mean

According to Holland et al. (2015), functions for which confidence is highest be given an 'A' rating and those for which confidence is less be given a 'B' rating. This is supplemented by '' for effects that are additive.*

The calculated health impacts of air pollution related to the shipping in the Baltic Sea Region is presented in Table 17. The 'All cause mortality effects from chronic exposure to NO2' has not been calculated as the population exposure to annual mean above 20 µg/m^3 is not available.

Table 18 shows the monetary valuation of the health impacts shown in Table 17. Valuation is performed by multiplying impacts (e.g. respiratory hospital admissions) by an appropriate estimate of the unit value of each impact (e.g. the cost of a respiratory hospital admission).

The monetized values of health impacts are taken from earlier studies. In the ARP model the highest health impact value, the Value of statistical life (VSL), range between 128,000 and 3.13 million EUR 2010 per avoided fatality from reduced exposure to air pollution, the Value of life year (VOLY) ranges between 45,000 and 155,000 EUR 2010 (Holland et al., 2005; Desaigues et al., 2011; OECD, 2012; Holland et al., 2013; CBI, 2011). As a confidence interval one can use the lowest value of VOLY (Desaigues et al., 2011) as the low range, the highest value of VOLY (mean value in CBI, 2011) as the mid-range, while the calculations of avoided fatalities using the highest VSL value (OECD, 2012) can be used as the high range value. The mid-range is then more conservative than the recommended value by OECD (2012).

Table 17: Health impacts of air emissions from shipping for the year 2012 based on the exposures calculated in this study with help of the ARP model.

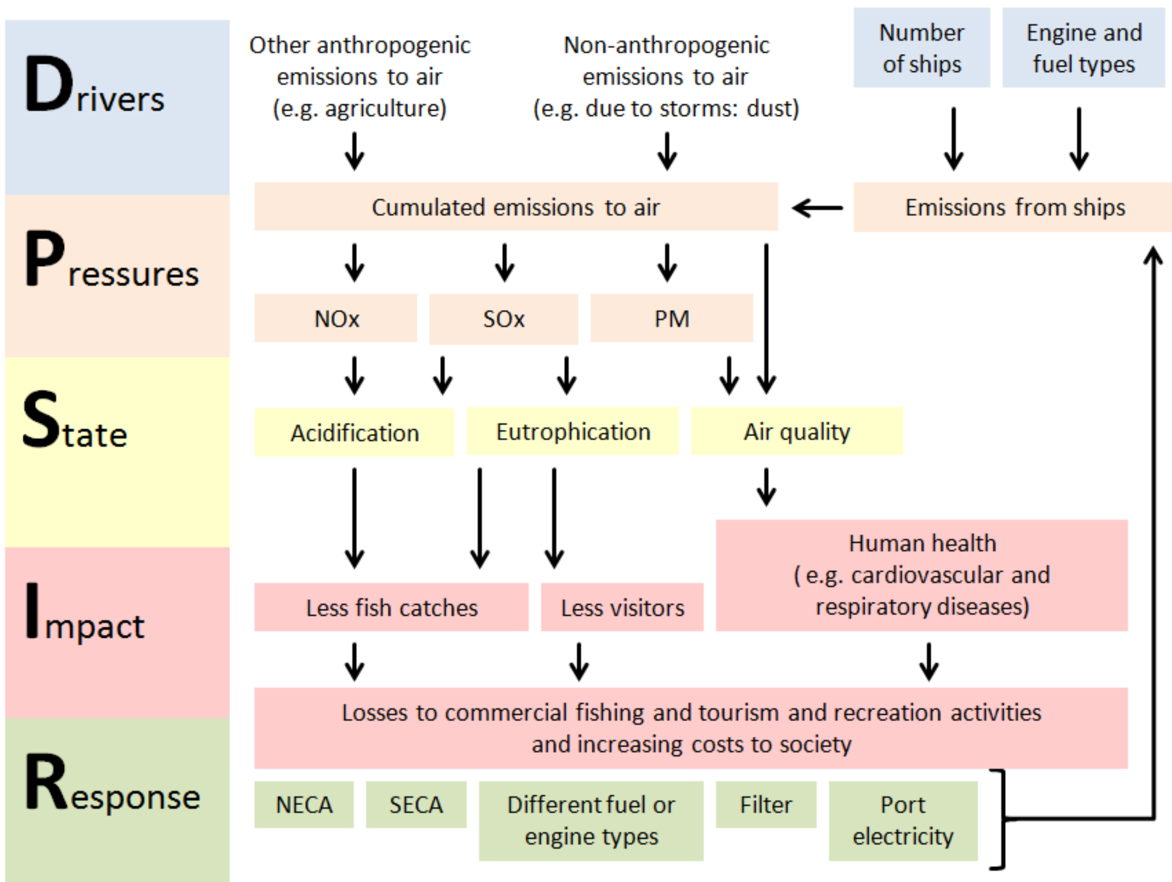
Pol-lutant	Impact	Unit	DE	DK	EE	LIT	LT	FI	SE	PL	TOTAL
O3	Acute Mortality (All ages)	Premature deaths	15	7	6	18	14	13	24	16	114
O3	Respiratory hospital admissions (>64)	Cases	12	6	3	10	5	21	19	9	86
O3	Cardiovascular hospital admissions (>64)	Cases	71	15	21	83	39	78	86	68	461
O3	Minor Restricted Activity Days (MRADs all ages)	Days	58 739	27 327	20 486	56 351	41 808	56 511	100 717	64 589	426 528
O3	*Chronic Mortality (all ages)*	*Life years lost*	114	52	47	144	105	105	174	139	881
O3	*Chronic Mortality (30yr +) deaths*	*Premature deaths*	12	5	5	15	11	11	19	13	91
PM	Chronic Mortality (All ages)	Life years lost	3 640	3 316	450	1 150	820	1 091	2 929	2 519	15 915
PM	Chronic Mortality (30yr +)	Premature deaths	390	315	44	107	82	103	296	216	1 554
PM	Infant Mortality (0-1yr)	Premature deaths	0.5	0.7	0.1	0.3	0.1	0.1	0.2	0.4	2.3
PM	Chronic Bronchitis (27yr +)	Cases	319	251	29	64	49	88	249	170	1 218
PM	Bronchitis in children aged 6 to 12	Added cases	890	1 022	102	224	158	325	939	585	4 246
PM	Respiratory Hospital Admissions (All ages)	Cases	158	107	17	55	36	60	88	92	614
PM	Cardiac Hospital Admissions (>18 years)	Cases	154	54	12	41	21	44	76	75	477
PM	Restricted Activity Days (all ages)	Days	371 611	369 983	42 279	97 663	71 469	128 731	369 566	220 638	1 671 940
PM	Asthma symptom days (children 5-19yr)	Days	10 185	11 700	836	1 831	1 292	2 660	7 673	4 782	40 960
PM	Lost working days (15-64 years)	Days	163 679	84 527	9 584	20 486	16 902	28 914	81 520	89 374	494 987
NO2	*Bronchitis in children aged 5 to 14*	*Added cases*	153	213	7	5	6	24	76	35	519
NO2	*Respiratory Hospital Admissions (All ages)*	*Cases*	50	50	7	6	8	18	59	31	230

Table 18: Valuation of the health impacts from Table 17 calculated with the ARP model for the year 2012, in EUR million 2010

			DE	DK	EE	LIT	LT	FI	SE	PL	TOTAL
Clean Air Policy Package Aggregation	VOLY	low	250	218	29	73	53	76	204	164	1 067
	VOLY	mid (median)	323	285	38	97	69	98	262	215	1 388
	VOLY	high	655	587	80	203	145	198	530	445	2 841
	VSL	low	563	454	63	152	116	153	433	314	2 248
	VSL	mid (mean)	1 057	853	118	288	221	283	808	588	4 217
	VSL	high	1 312	1 059	148	360	276	352	1 002	729	5 237
Effects from acute NO2 and chronic O3 exposure	VOLY	low	6	3	2	7	5	5	9	7	44
	VOLY	mid	8	4	3	9	7	7	12	10	62
	VOLY	high	19	9	8	23	16	17	28	22	141
	VSL	low	16	8	6	18	14	13	24	16	115
	VSL	mid	32	14	12	37	28	27	48	33	230
	VSL	high	39	18	16	46	35	34	60	41	289

According to defined ranges, we can summarize that the costs of health impacts by shipping are estimated by about EUR 2.8 billion per year. The calculations are based on the TSAP methodology and include the air emissions: ozone and PM for the year 2012. The health impact costs are ranging between a maximum of 1.1 and a minimum with EUR 5.2 billion per year. The sensitivity study on effects from acute NO_2 and chronic O_3 exposure was calculated with between EUR 44 and 289 million per year, with a mid range of EUR 141 million per year but are partially overlapping with the results according to TSAP methodology.

Figure 27: DPSIR – Shipping air emissions in the Baltic Sea



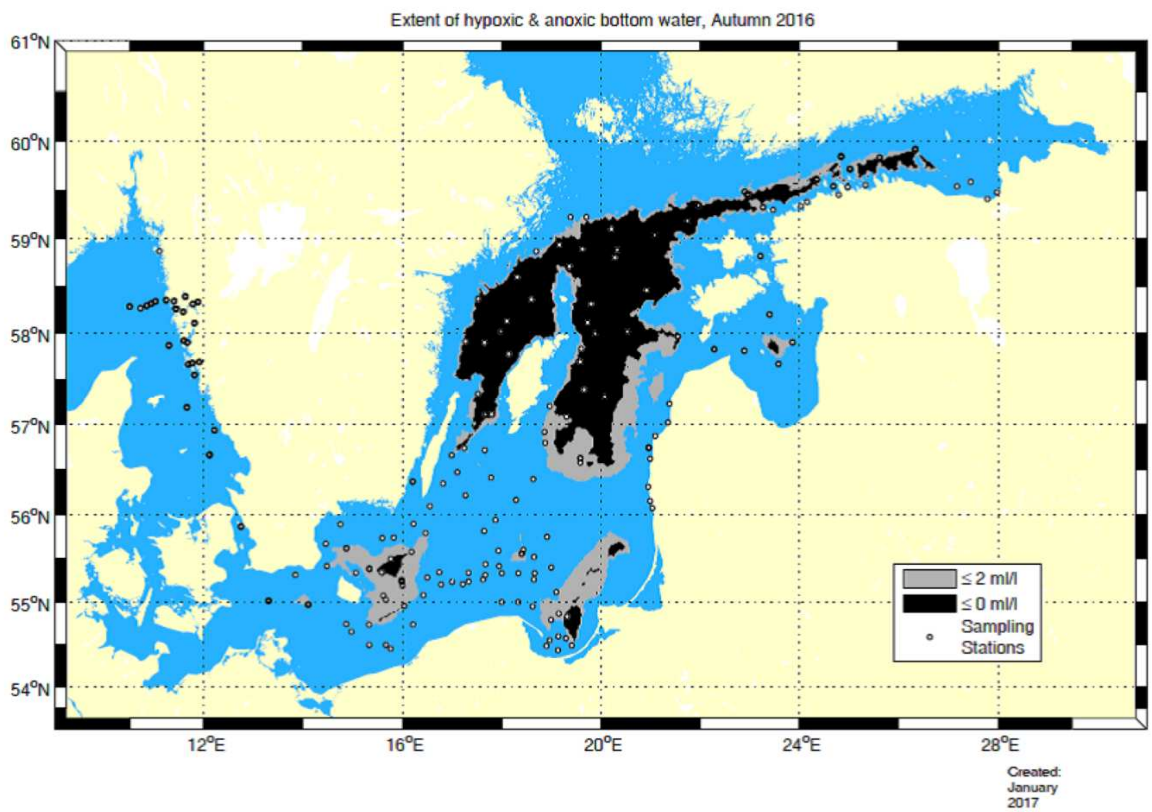
Note: The figure provides an example of how air emissions from shipping in the Baltic Sea can be understood using the DPSIR framework. It is not exhaustive.

3.2.5 Case Study: The impact of nutrients from shipping on cod reproduction in the Baltic Sea

This section is used to assess the impact of nutrient contribution from shipping (all ship types) on the cod-spawning areas and cod population in the Baltic Sea. Eutrophication in the Baltic Sea is to a large extent driven by anthropogenic input of the nutrients Nitrogen (N) and Phosphorous (P). Nutrients from shipping are mainly added to the sea in form of atmospheric deposition of NO_x but also in smaller proportions from sewage (N and P) and food waste (N and P). In this case study we investigate the effects of nutrients from shipping on microalgal growth. When algae decompose oxygen levels in bottom waters will decrease and affect spawning of cod and the cod stock. Cod is the top predator in the Baltic Sea food chain as well as highly important to commercial fishing and food provisioning.

The Baltic Sea has brackish water, with decreasing salinity from west to east and from south to north. The Baltic Sea is an enclosed sea area with high nutrient loads reaching the water body from agriculture, industries and river run-off. The high nutrient content favors growth of phytoplankton/microalgae which can lead to algal blooms. During decomposition of decaying algal biomass after blooms, the oxygen requirements in the deeper waters are high which leads to oxygen-depletion. As the Baltic Sea has limited exchange of water with surrounding sea areas the bottom-water is seldom replaced and problems with low oxygen levels in the bottom layers are increasing over time (see Figure 28).

Figure 28: Areas of low oxygen in bottom waters



Source: SMHI, 2016.

Cod is feeding on herring *Clupea harengus* and sprat *Sprattus sprattus*. While cod feed on adult sprat, sprat can on the other hand feed on the younger stages such as egg and larvae of cod (Nissling et al 2004). All three fish species (cod, herring and sprat) also prey on zooplankton (mainly copepods *Acartia* spp.). Cod reproduce in the Baltic Sea and their eggs require certain threshold-values of both salinity and oxygen for development. The cod spawning can occur during 6 to 7 months but with peak spawning during 1-2 months (Bleil et al 2009). The spawning starts earlier in western parts of the Baltic and later in more eastern parts of the Baltic. The cod in Kiel Bay and Mecklenburg Bay have the spawning peaks in February-April (Bleil and Oeberst, 2004; Bleil et al., 2009), in the Arkona Basin, peak spawning occurs both in February-April and and June-July, while Bornholm Basin cod peak in July-August (Wieland et al., 2000; Bleil et al., 2009). Further to the east in Gdansk Bay the peak spawning is in August (Kändler, 1949).

The long spawning season in the Arkona Basin, support the theory that Arkona basin may be a spawning ground for both Western and Eastern Baltic cod stocks (Bleil and Oeberst, 2004). The eastern Baltic cod stock is present east of the island Bornholm, Denmark, and the western Belt Sea cod stock, present in the Arkona Basin and the Belt Seas (Figure 31). The major cod stock in the Baltic Sea, the eastern Baltic cod, has decreased substantially during the last decade. The decrease since the 1980s is believed to be both due to overfishing and degradation of spawning areas (Figure 29). Decline in spawning areas are due to oxygen depletion in the deeper water in the eastern part of the Baltic Sea (ICES 2012). A method to calculate this is by use of Area of Occupancy estimation of reduction in population size due to spawning habitat loss (Table 19).

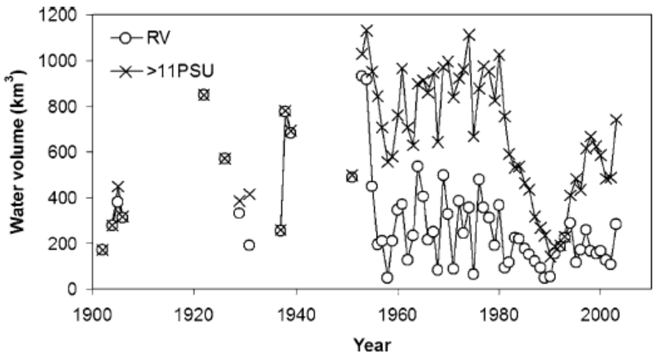
Table 19: Spawning season of individual cod stocks, listing the time of peak spawning, and references to sampling

Area	Spawning season	Peak spawning	Years	Method	Reference
Kattegat	Sept.–May	Jan./Feb.	2002/2003	Histology[a]	Vitale et al. (2005)
Sound	Nov.–May	Jan./Feb.	2002/2003	Histology	Vitale et al. (2005)
Kiel Bay	Jan.–June	Feb./Mar.	1934–1943	Plankton[b]	Kändler (1949b)
	Jan.–June	Mar.	1964–1969	Adults[c]	Thurow (1970)
	Dec.–July	Mar./Apr.	1970/1971	Plankton	Müller (1988)
	Feb.–May	Mar./Apr.	1992–2005	Adults	Bleil et al. (2009)
Mecklenburg	Feb.–May	Apr.	1934–1943	Plankton	Kändler (1949b)
	Feb.–June	Mar./Apr.	1992–2005	Adults	Bleil et al. (2009)
Arkona	Feb.–Aug.	Feb./Apr.	1934–1943	Plankton	Kändler (1949b)
	Mar.–Sept.	June/July	1992–2005	Adults	Bleil et al. (2009)
Bornholm	Mar.–Oct.	July/Aug.	1934–1943	Plankton	Kändler (1949b)
	Mar.–June	May/June	1969–1985	Plankton	Wieland et al. (2000)
	Mar.-Nov.	July/Aug.	1986–1996	Plankton	Wieland et al. (2000)
	Feb.–Nov.	July/Aug.	1992–2005	Adults	Bleil et al. (2009)
	Mar.-Sept.	July	1995–1997	Adults	Tomkiewicz and Köster (1999)
Gdánsk	Mar–Oct.	Aug.	1934–1943	Plankton	Kändler (1949b)
Gotland	Apr.–Aug.	May	1934–1943	Plankton	Kändler (1949b)

Source: Hüssy, 2011

Note: a: Histology, histology of gonads; b: Plankton, ichthyoplankton surveys; c: Adults, survey of adult maturity

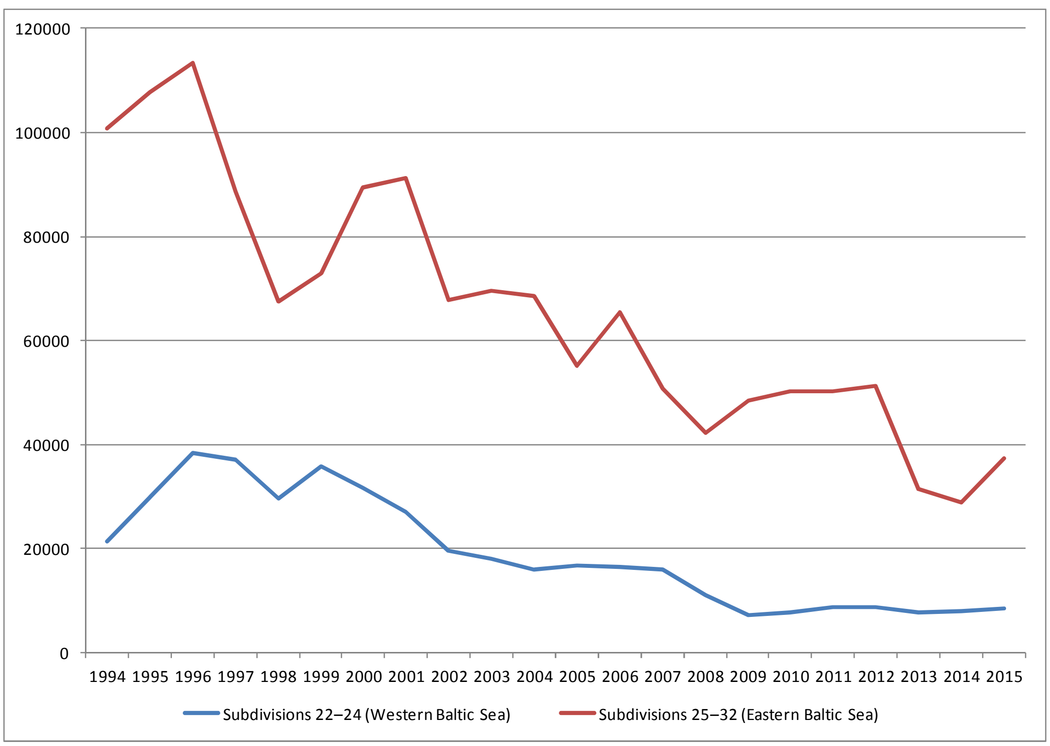
Figure 29: Historical decrease in cod reproductive volume



Source: Österblom et al (2007)

Note: The cod reproductive volume (RV, > 11 PSU and >2 ml O_2/l) in the Baltic Sea from year 1900 onwards. Before 1950, the entire volume of water with a salinity high enough for cod reproduction (>11 PSU) was mostly well oxygenated and available for cod reproduction. After 1950, the volume of water above 11 PSU is on average large than before 1950, but the RV is lower, indicating that the decrease in RV was caused by eutrophication induced oxygen deficiency and not by decreased inflows of saline water.

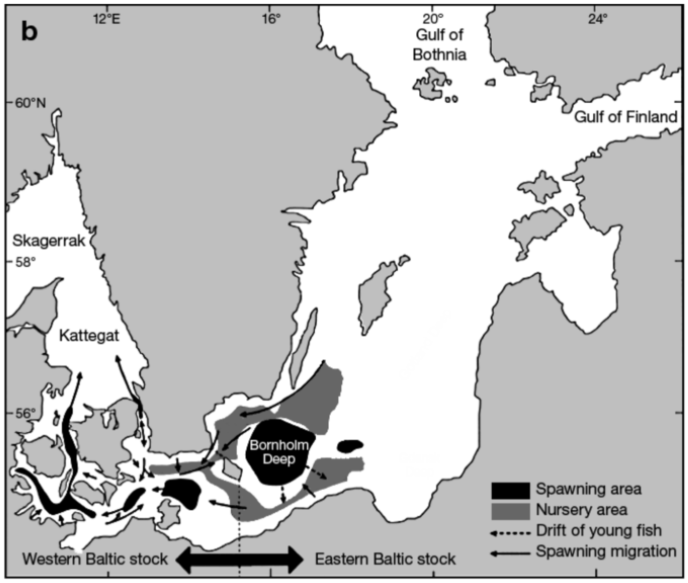
Figure 30: Commercial landings of Cod (Gadus morhua) in the Baltic Sea (1994 – 2015) (tones)



Source: ICES, 2016

The modelling of nutrients in this case study was conducted for the whole Baltic Sea area as deposition of NOx from ship air-emissions is expected to be distributed in the whole area. However, the areas in focus for the cod reproduction in this work are the Arkona basin[9], Bornholm Deep and Gdansk bay where the Eastern Baltic cod stock has major spawning areas (Figure 31). For the calculations performed in this work the spawning period July to September were considered for Arkona Basin, Bornholm basin and August to October for Gdansk bay.

Figure 31: Reproduction areas for cod and division between western and eastern cod stocks.



Source: Cardinale and Svedäng, 2011

In general, nitrogen and phosphorous enter the Baltic Sea from various sources; with dominating contribution from land. Waterborne annual inputs of nutrients to the Baltic Sea amount to about 977,000 tonnes (t) of nitrogen and 38,300 tonnes of phosphorus, where average annual atmospheric deposition of nitrogen is about 218,600 tonnes (HELCOM 2013). The contribution of NO_X to the Baltic Sea comes from combustion and transportation.

Nitrogen-contribution from Baltic shipping NOx emissions in 2010 was 13,523 tonnes which equals the contribution from a boundering country, (as examples Sweden 14,207 tonnes) and the contribution from shipping is approximately 6 % of the total atmospheric nitrogen load (HELCOM 2013). Nitrogen, together with Phosphorous is used by phytoplankton/microalgae for growth and when in excess this can lead to algal blooms. Nutrients from other shipping-sources, sewage (N and P) and food waste (N and P) are small, in comparison to NOx emitted to air. The contribution of nitrogen in black and greywater is 491 tonnes and of phosphorous 164 tonnes, which equals 0.05 % of total N and 0.43 % of total P (Havsmiljöinstitutet 2014).

The ratio of N:P is relevant for the algal blooms and requirements for algal growth are supplied in the ratio 16:1. There has been debate in the Baltic Sea region if reduction of one of the nutrients (N or P) then could be a way forward in the mitigation process. Phosphorous, however is also “stored” in the sediments and can under certain conditions reach the water mass and become available for phytoplankton. This supply of phosphate is larger from sediments with low oxygen as the anoxic conditions promote the flux of phosphate from the bot-

[9] The study focuses on the Eastern Baltic cod stock spawning. However, this will impact the cod stocks in the entire Baltic Sea.

tom sediments (Emeis et al 2000, Conley et al 2002). However, as the Baltic Sea is stratified the nutrients in deep water and sediments will not be directly available to the algae in the same way as nutrients deposited on the surface.

In this case we consider the nutrients Nitrogen (N) and Phosphorous (P) as pollutants. Marine microalgae (phytoplankton) require N and P to grow together with sunlight and temperatures over certain thresholds. The diatoms will in addition need silica. High nutrient loads will lead to high biomass of microalgae. There are different types of algal blooms in the Baltic Sea. The spring bloom occurs in March-April in Arkona and Bornholm basins (Wasmund et al 1998), and the bloom microalgae consists mainly of diatoms and dinoflagellates (Wasmund et al 1998) which after the bloom die and sink to the sea floor. During decomposition of dead algae, much oxygen is required by the bacteria responsible for decomposition and mineralization. The areas where algal blooms are decaying will therefore become oxygen-depleted. N and P contribution from shipping contributes to the already high nutrient concentrations in the Baltic Sea

Cod recruitment depends on the volume of water in the deep basins with a salinity >11 PSU and an oxygen content >2 ml O_2 /l which are required for cod egg survival (Vallin et al. 1999). This reproductive volume (RV) is influenced negatively by eutrophication, due to increased oxygen consumption in the bottom water during decomposition of algal bloom biomass. With the GETM-ERGOM the relative contribution of low oxygen area due to shipping nutrients have been calculated for the bottom layer in three most relevant cod spawning areas (Figure 32 and Figure 33).

Figure 32: Oxygen in the bottom layer in the Arkona basin (turqoise line), Bornholm basin (blue line) and Gdansk basin area (yellow line) for 1st August 2012,in ml O_2/l

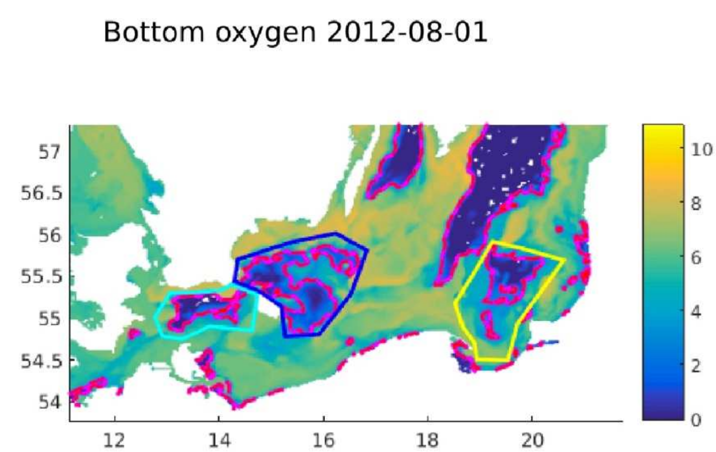
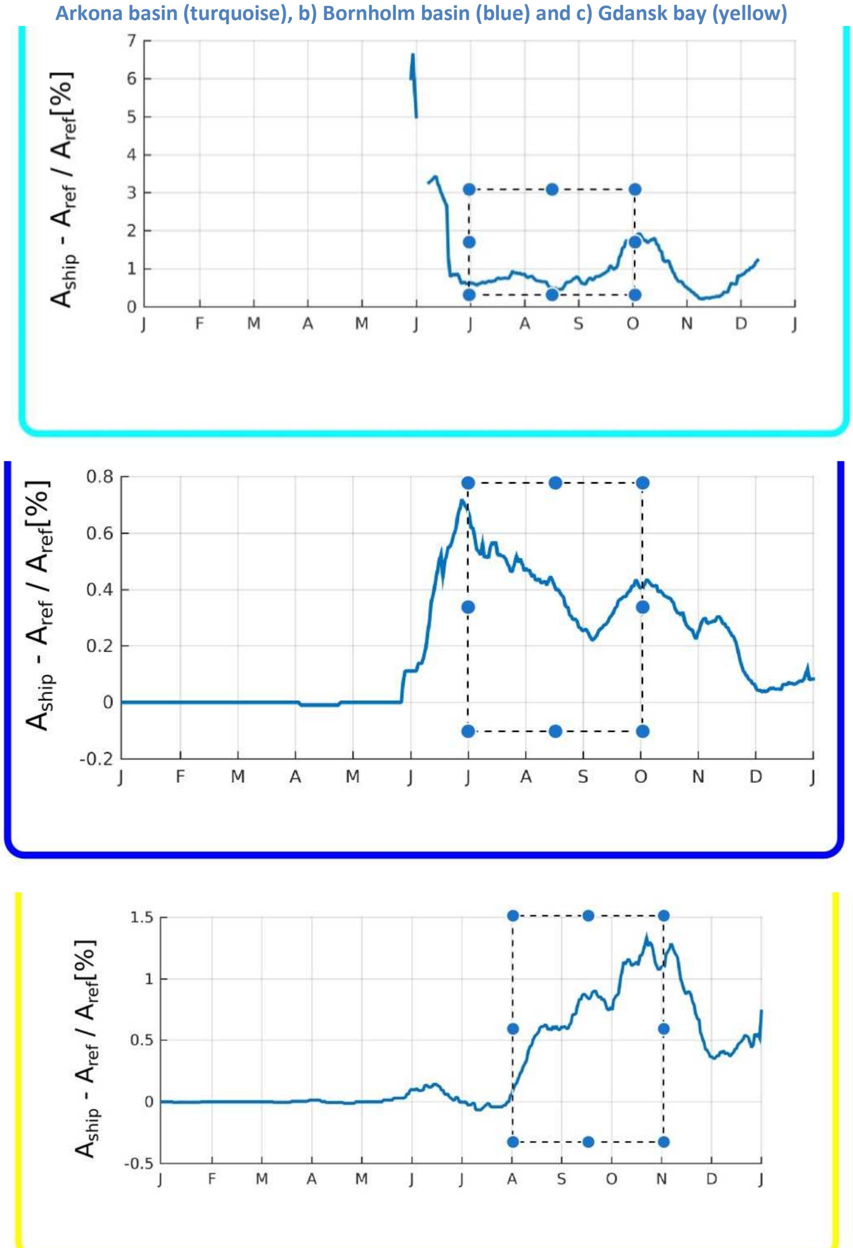


Figure 33: Increase in hypoxic area (decrease in available area for successful spawning) during peak spawning season for cod Arkona basin (turquoise), b) Bornholm basin (blue) and c) Gdansk bay (yellow)



The maximum increase in area of oxygen-depletion (under 2 ml O_2/l) due to shipping was found to be for the Arkona basin (turqoise) July/August/September about 1.8 %, Bornholm basin (blue) July/August/September about 0.4 % and Gdansk basin area (yellow) August/September/October about 1.3 %.

The maximum average hypoxia area increase (which corresponds to decrease in area for successful cod egg development) over most relevant cod spawning areas and months is about 1.2 %. The calculations are based on the major spawning grounds for the Eastern Baltic cod stock. The relative difference in area with hypoxia will be sensitive to the size of reference area and in the calculations a maximum possible increase over the 3 months of most likely spawning interval has been used.

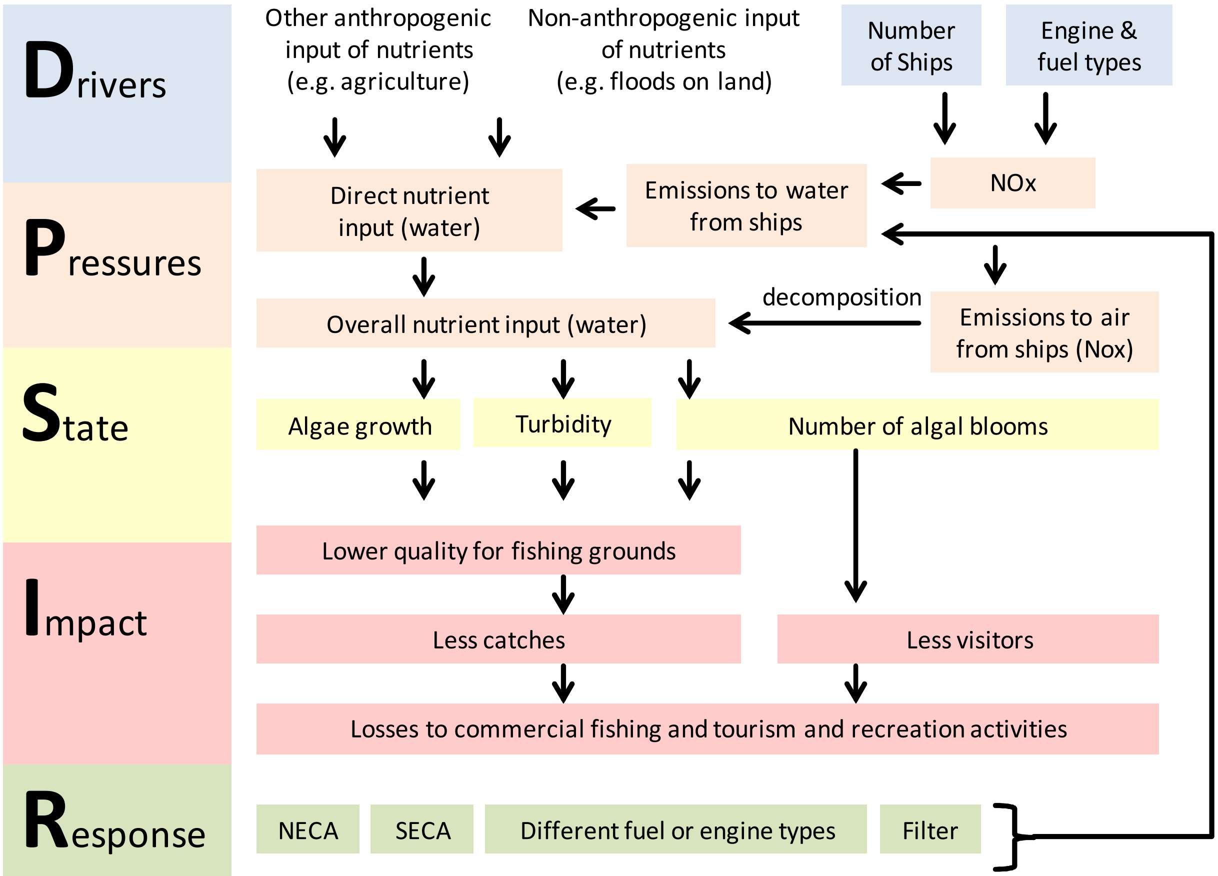
The impact can be seen in reduced cod stocks and therefore lower landings by commercial, as well as recreational fishers. This assumes that NOx is evenly distributed within the Baltic, therefore not taking into account surface currents and oceanography. Similarly, this assumes that cod eggs are evenly distributed in the spawning area. Based on the possible 1.2 % decrease in cod population (caused by reduced reproduction due to algal blooms/oxygen depletion from shipping nutrient contribution) the decreased value and amount of landed cod (Zeller et al. 2011) can be calculated.

Therefore, one can assume that a 1.2 % decrease in cod population in 2012 directly equates to a 1.2 % decrease in overall fisheries landings in the Baltic Sea for that year. According to ICES, 2016 (Figure 30) total commercial landings of cod in the Baltic Sea was 59,879 tonnes. The 1.2% decrease equates to a difference of 719 tonnes and a potential total of about 60,597 tonnes that would have been landed in the absence of shipping NO_x emissions. According to data from the European Market Observatory for Fisheries and Aquaculture Products (EUMOFA, 2017) the landings value of cod for Baltic Sea countries[10] in 2012 was about 1,884 EUR per tonne, suggesting an overall loss in value of landings of 1,353,000 EUR in 2012 to those countries. However, in order to validate the results, the sensitivity of the economic numbers was tested. For the span of years between 1994 to 2015, the minimum price was about EUR 1,607 per tonne and the maximum price was about 2,230 EUR per tonne. This provides a possible range of overall losses between EUR 1,155,000 and EUR 1,602,000 for the year 2012.

A number of coming regulations have the potential to reduce NO_x and mitigate its effects on marine environment and cod stocks. 22,000 tonnes N is the expected N-reduction when NECA (Baltic and North Seas) is fully effective. 7,000 tonnes is estimated to be reduction from direct deposition to the Baltic Sea surface and the remaining 15,000 tonnes is estimated to be reduced from deposition to the landmasses draining into the Baltic Sea. However as stated above it will be the ratio between Nitrogen and Phosphorous that is of importance for algal growth, why the reduction of the load of NO_x has to be set in relation to the relevant load of phosphorous for the area of interest.

[10] Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, and Sweden.

Figure 34: DPSIR – Water emissions from shipping in the Baltic Sea



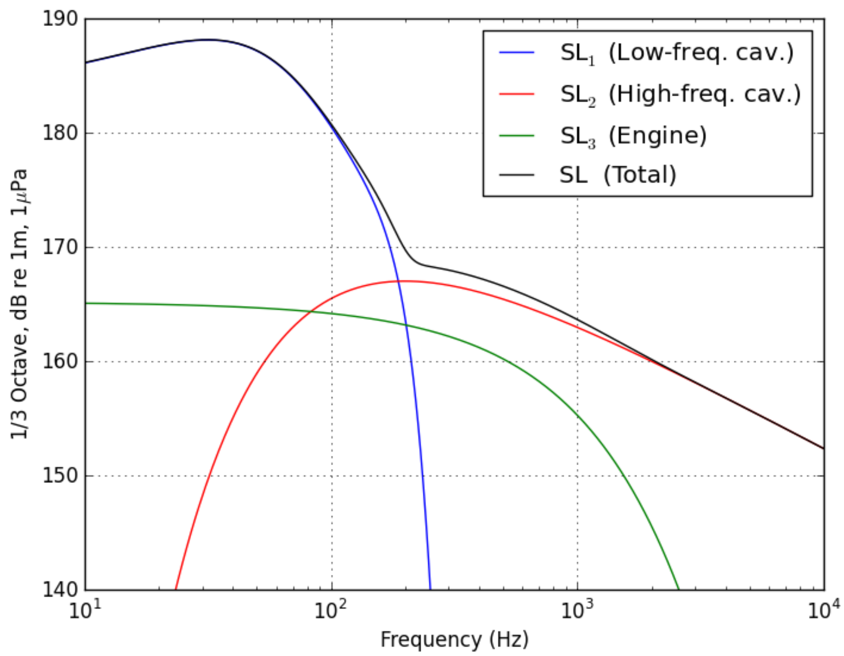
Note: The figure provides an example of how water emissions from shipping in the Baltic Sea can be understood using the DPSIR framework. It is not exhaustive.

3.2.6 Case Study: The impacts of underwater noise from ships in the Baltic Sea

Scientific results unequivocally suggest that animals react to sound and sometimes with devastating results. However, it is more common that noise leads to strong avoidance reactions in animals. It is likely that the levels of underwater sound, and therefore associated effects on the marine ecosystem have been increasing since the advent of steam-driven ships, although there have been very few studies that have quantified these changes. Undoubtedly, the effects of undewater noise must be better understood to effectively manage it in the future. The boundary of the Baltic Sea in the west is the parallel of the Skaw at 57°44.8'N. This separates the Baltic Sea from the North Sea. This is also the area defined as Particularly Sensitive Sea Area. For underwater noise, no international legislation exists in the area.

The main cause of noise from ships is engine operation (loud continuous noise from 10 Hz to 10kHz, see Figure 35. According to van der Graaf et al. (2012) leisure boats are not considered as a driver for underwater noise. Normal operation of a ship generates underwater noise which consists of low and high frequency cavitation and machinery noise. The source levels of sound emissions from a ship can exceed 180 dB (re 1m, 1 mPa) (Figure 35) and sounds can transfer long distance in water. For example in monitoring stations in the Gulf of Finland and in the Great Belt the noise caused by ships always exceeded all natural background when the ships were closer than 5 km (Sairanen 2014). Within the MSFD, underwater noise is defined within a range from 10 Hz to 10 kHz. However, some mammals (like e.g. harbor porpoises, seals) are sensitive to sounds up to tens of kHz (Van der Graaf et al., 2012) which are then left out of the spectrum of MSFD Descriptor 11 on Energy incl. underwater noise.

Figure 35: Sound emissions from ships



Source: Sigray & Pajala, 2015.

Shipping is but one source of underwater noise. Human activities like dredging, construction, explosions, pile driving, seismic exploration, sonars and pleasure boats also emit noise. Further, there are natural sounds from wind, waves, thunder, volcanic activity and sea ice, which contribute to noise. Contributions of these sources are not included in this study, but studies of shipping as a noise source will enable further studies of noise source apportionment.

The soundscapes in the Baltic Sea close to the coastline and in the archipelagos are not well known, and currently it is not possible to estimate in detail how often anthropogenic noise exceeds the natural background sound levels. However, coastal areas and archipelagos apparently include most of the biodiversity and they are also important e.g. for reproduction of certain life history stages of species that are typical for the pelagic areas. It is apparent that the lowest sounds from the marine traffic do not well propagate in shallow water, but this issue is more highlighted in the deliverable 4.7of SHEBA.

Close to a ship the noise sound pressure levels (SPL, Pa re 1 µPa) can apparently reach much more than 100 dB above the baseline thresholds of marine fish species (see audiograms in Figure 36). However, fish may be able in some degree to avoid noisy environments. Though impacts of marine traffic noise on fish behavior is poorly understood although e.g. Atlantic herring (Clupea harengus) and cod (Cadus morhua) have been observed to avoid approaching ships via horizontal and vertical movements (Soria et al. 1996, Vabø et al. 2002, Mitson and Knudsen 2003 and references therein). Any additional and particularly long lasting physiological activity (like swimming long distances when avoiding approaching ships) is likely to decrease growth or reproduction of the species, induce mortality and noise may e.g. delimit species' ability to inhabit the marine habitats e.g. with most abundant food resources.

Marine mammals and fish and also some invertebrates are sensitive to underwater noise. Four mammalian species inhabit the Baltic Sea. These are harbour porpoise, grey seal, ringed seal and harbour seal. The fish diversity is larger in the western parts of the sea where marine fish species are abundant whereas freshwater species are dominant in the areas where salinity is low. In Kattegat c. 176 species have been found, in eastern Gotland Basin 82, and in the Bothnian Bay 50 species (Arendal et al. 2012). Marine fish species i.e. herring, sprat and cod are the most abundant species and also the most important ones for fisheries. Fishing on some other marine species, salmon and freshwater species is locally important and valuable particularly for recreational fisheries.

A recent extensive review by Schack et al. (2016) highlights the sensitivity of the animals in the Baltic Sea to underwater noise. This review considers both impulsive and continuous noise, and states:

> *Continuous noise can likely affect harbour seals, ringed seals, cod, sprat and herring due to masking of important communication signals especially during mating/spawning seasons, and for seals, cod, sprat, herring and European eel also through masking of important acoustic migratory cues and conspecific communication. For harbour porpoises there may be some effects on sound production, and masking of migratory cues may also occur, but the significance of the latter is still unknown. For all species prolonged exposure to continuous noise may also result in negative long-term effects due to increased levels of stress hormones.*

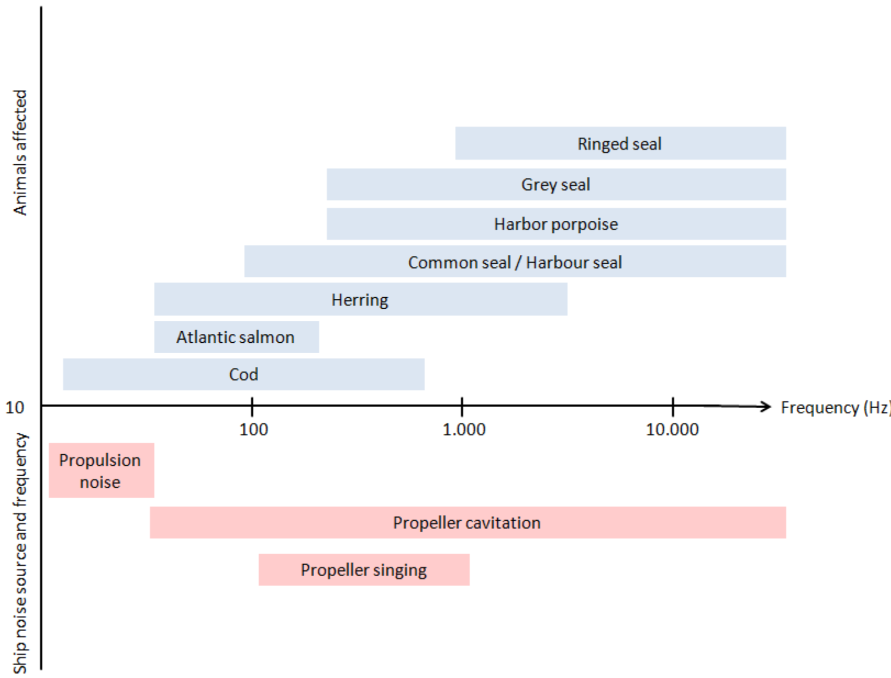
The results from the recent BIAS project[11] support that noise from shipping at least at times influence almost all open sea areas of the Baltic Sea. Close to the main shipping lanes the noise is more or less continuous. Besides, the frequencies and levels of the noise from marine traffic overlap the hearing ranges of fish and mammals in the Baltic Sea (see Figure 36). For a large fraction of Baltic Sea fish species the audiograms have not been determined (Schack et al. 2016) and little is known about the impacts of noise and about hearing of invertebrates or eggs, larvae and young stages of fish (Popper et al. 2014).

The potential impact of underwater noise on marine mammals of the Baltic Sea has recently been reviewed in HELCOM report Noise Sensitivity of Animals in the Baltic Sea (HELCOM 2016b). The harbor porpoise has an exceptionally sensitive hearing and it relies on sound as its primary sensing method (Andersen 1970). The seals on the other hand live an amphibious life, and their physiology is adapted to hearing in both air and water. They are therefore also susceptible to anthropogenic noise such as shipping noise in both above and below the sea surface.

Hearing threshold audiograms have been produced for various animals living in aquatic environment. These describe the frequency specific sound levels (in dB) which the animals can hear (see Figure 36). The audiogram data is potentially only an indication that the sound was heard. Thresholds of harmful noise levels can not be constructed from audiogram data alone.

[11] See https://biasproject.wordpress.com/

Figure 36: Audiogram for selected species and ship compartments



Source: based on Chapman & Sand, 1974; Enger, 1967; Kastak & Schusterman, 1996; Nedwell, 2004; Madsen et al., 2006; Ridgway & Joyce, 1975; Terhune & Ronald, 1975

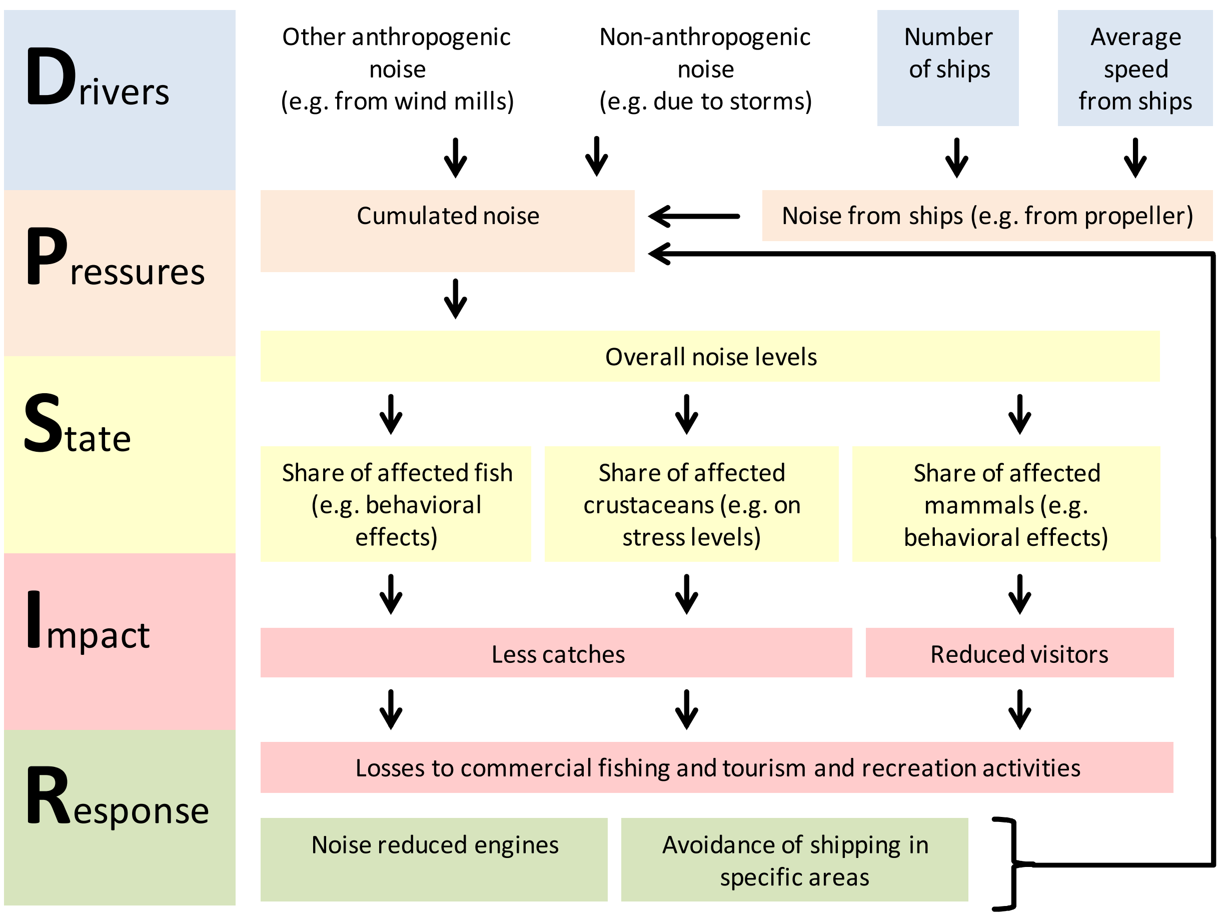
Currently, it is very challenging to estimate the impacts of shipping noise on single aquatic species in the Baltic Sea and further to derive reliable estimates about impacts on ecosystem services. Even a more holistic approach considering species interactions would be desirable but even more difficult an approach than impact on single species level. Species have interactions and they form complex networks i.e. food webs, which also interact with the abiotic components of the sea forming the ecosystem. Changes on a species level cascade up and down along the food-web making it a challenging task to forecast shifts in the food web or on the ecosystem level.

The species diversity could be an issue to consider in noise impact and risk assessments. The Baltic Sea has notably low species diversity, and only a handful of species dominate the ecosystem in biomass and numbers (Johannesson et al. 2011). Species have different roles in the ecosystem. In the Baltic Sea, important ecosystem functions are upheld by single or a few species (Johannesson et al. 2011). Still the biological productivity in the Baltic Sea is not much lower than in the adjacent North Sea that has a multiple number of species (Elmgren and Hill 1997). But unlike in species-rich systems, elimination of one species from the Baltic Sea (in particular a keystone species – one playing unique and crucial roles in the way an ecosystem functions), even dramatic changes may take place in the structure and function of the ecosystem and in the ecosystem services provided (Elmgren and Hill 1997, Johannesson et al. 2011). Moreover, the keynote species can be different in the different areas of the Baltic Sea as marine species diversity decreases from the more saline western areas towards the northern and eastern parts where freshwater fauna becomes dominant.

Furthermore, for example, the herring stock in the Baltic Sea is known to consists of many local spawning populations which can mix during feeding but segregate during reproduction season (Jørgensen et al., 2005b). They may disappear (e.g. due to fishing or unfavorable environmental changes) from certain locations but later again recolonise those areas as well as other suitable habitats (Jørgensen et al., 2005a). Underwater noise may influence connectivity of marine populations and habitats. Fragmentation and loss of suitable habitats may influence the extirpation of populations and their capacity to recolonize marine space (Reed, 2004).

The ecosystem service which fish stocks most obviously contribute to are commercial and recreational fisheries. Furthermore, multiple ecosystem services rely on healthy and productive fish stocks (Holmlund and Hammer 1999). Fish stocks provide food resources for higher trophic levels and thus they transfer energy and material from lower to higher levels and are thus essential in the marine ecosystem. They may also essentially contribute to the ecosystem's capacity to absorb and resist disturbance and contribute to maintenance of water quality desirable for human well being (e.g. Casini et al., 2008, Hessen & Kaartvedt, 2014). Thereby fish stocks influence a number of ecosystem services relying on good water quality. Fish stocks also contribute to recreational fisheries and they have existence value. They provide gene resources which in future may prove valuable. If underwater noise is detrimental to fish stocks a multitude of adverse changes in ecosystem services will take place.

Figure 37: DPSIR – Shipping noise in the Baltic Sea



Note: The figure provides an example of how underwater noise from shipping in the Baltic Sea can be understood using the DPSIR framework. It is not exhaustive.

3.2.7 Summary on ecosystem services assessment

The previous sections aimed to assess the costs of degradation and impacts on human well being i.e. losses of ecosystem services in the Baltic Sea caused by pressures stemming from the shipping sector. To do this, an assessment framework (see Figure 1) based on the DPSIR framework was applied in an effort to trace the linkages within the framework and identify specific points where changes, or potential changes could be measured. Literature, policy reports, statistical databases, and expert opinion provided the basis for the assessment. The assessment linked both qualitative and quantitative data in order to provide a comprehensive picture, but also to work around the lack of quantitative and comparable data. The broad categories focused on the pressures created by shipping, changes to the state of Baltic Sea environment, and potential costs of degradation (i.e. changes to ecosystem services and human health). The application of scenarios enabled a look into how these pressures may impact ecosystem services and human well being in the future. In addition to the application of the assessment framework, three specific case studies were selected in order to take an in-depth look at how specific pressures from shipping potentially impact ecosystem services and human well being.

Numerous pressures (see section 3.2.1) stemming from shipping are relevant and leading to changes in the state of the Baltic Sea environment. Pressures range from emissions to air and water, as well as underwater noise and physical impacts. Their relative importance is determined by the proportion of shipping contributing to the pressure compared to other drivers, e.g. agriculture or land based transport. Of the pressures identified from shipping, several can be identified as significant in the sense that the contribution of shipping to this pressure is high and that the trend is expected to increase. For example, shipping is deemed highly important to the introduction of non-indigenous species as well as physical impacts (i.e. from anchoring, mooring and movement caused by ship wakes), while to a lesser degree important pressures are NO_X, PM, and underwater noise. However, this is not to say these pressures are leading to the highest level of changes to the state of the environment or have the highest costs for human well being. For example, the importance of CO_2 emissions to global climate change means that shipping along with other drivers is contributing to significant impacts on the global level, requiring policy makers to consider multiple drivers to tackle the issue. A similar argument can be made for contaminant emissions to water. Oil spills, however, represent a different challenge. While the pressure is believed to be decreasing in overall occurrence, this acute pressure, in which shipping accidents would be the primary cause, has the potential to cause significant and devastating changes to the state of the environment.

Changes to state (see section 3.2.2) are the culmination of pressures which lead to a physical change of the environment. Particularly relevant to shipping include invasive alien species, noise levels, oil spills (though expected to decrease) and to a lesser degree loss of coastal vegetation, acidification and eutrophication. This ultimately has the potential to lead to losses in important ecosystem services and impact human well being due to losses in ccommercial fishing, recreational fishing, genetic resources, climate change mitigation, coastal protection, tourism and recreation, other socio-cultural services, and impacts on human health (see section 3.2.3). In particular, costs of degradation generated by shipping to recreational fishing are potentially significant (i.e. due to eutrophication and oil spills) because the economic importance of recreational fishing may be substantial for local communities. Costs generated by shipping are also potentially significant to genetic resources, which can be greatly influenced especially by invasive species. Tourism and recreation, and other socio-cultural services also face potential costs generated by shipping. Finally, costs to human health in selected local settings could also be significant.

Case studies were used in an effort to take a closer at look specific pressures resulting from shipping in order to identify how they lead to direct impacts on human well being. Enhanced levels of air emissions and pollutants can lead to an increased risk for respiratory and cardiovascular diseases. Shipping contributes to this increased risk because of its contribution to the concentrations of relevant substances. The case study identified that the release of ozone and PM by shipping in the Baltic in the year 2012 impacts human health with EUR 2.8 billion (ranging between EUR 1.1 and 5.2 billion). In regard to emissions to water, the case study reviewed potential effects on cod spawning areas due to nutrients, specifically NO_X emissions. According to the assessment, the potential economic losses to the commercial cod fishing sector for 2012 could range between EUR 1.15 and 1.60 million. Regarding the impact of noise, the current available level of scientific information impedes a full assessment and identifying an impact on human well being. Nevertheless, the case study clearly indicates that underwater noise levels impact underwater species, what could lead to losses to sectors such as commercial fishing and recreational fishing.

Looking at potential future scenarios (see page 59 and Table 14) provides an indication of how pressures from shipping could lead to changes in the Baltic Sea and how this translates into impacts on human well being over time. The sustainability scenario (*SSP1*) used suggests that, compared to BAU, all pressures are expected to decrease, only pressures such as NO_X emissions, non-indigenous species and oil spills, would likely stagnate. Overall, in regard to effects on human well being, this would translate to decreasing costs or a leveling off of costs compared to BAU. On the other side of the spectrum, the fragmentation scenario (*SSP3*), suggests that when compared to BAU pressures such as CO_2, NO_X, SO_X emissions, PM, non-indigenous species, contaminants to water and oil spills, are likely to increase leading to predominantly increased costs to human well being.

In addition, the single scenarios (see page 61 and Table 15) provide an indication of changes to human well being based on selected parameters for pressures compared to BAU.

Air emissions are influenced in almost all of the single scenarios, only *Zero emissions to water scenario* has no influence on the different types of air emissions compared to BAU. Air emissions are decreasing in *Slow steaming*, *LNG* and the *Port measures scenario*. The most of them are including all types of air emissions and also link to all components of human well being. The *NoNECA 2021 scenario* would lead to an increase of NO_X emissions which is especially influencing the provisioning services, the cultural services and human health. *LNG scenario* shows a diverse picture, as PM, SO_2 and NO_X would decrease, CO_2 slightly decrease but CH_4 emissions would increase. The *Modal shift from land to sea scenario* will increase the CO_2 emissions of shipping significantly and influence all the analysed components of human well being, but it will decrease road traffic and it's emissions significantly.

Water emissions are influenced compared to BAU by a range of single scenaries: *Slow steaming*, *Modal shift from land to sea*, and *Zero emissions to water*. With *Slow steaming* and *Modal shift from land to sea* two of them are increasing emissions to water and are increasing the costs of degradation for all components of human well being. The *Zero emissions to water scenario* is the only scenario decreasing emissions to water and decreasing the costs to all components of human well being.

Underwater noise emissions are influenced by a variety of single scenarios compared to BAU: *Slow steaming* and *Modal shift from land to sea*. In parallel to water emissions, the *Slow steaming* and *Modal shift from land to sea* are increasing the pressure underwater noise as it increases the number of vessels.

3.3 Calculated Abatement Costs of Shipping in the Baltic

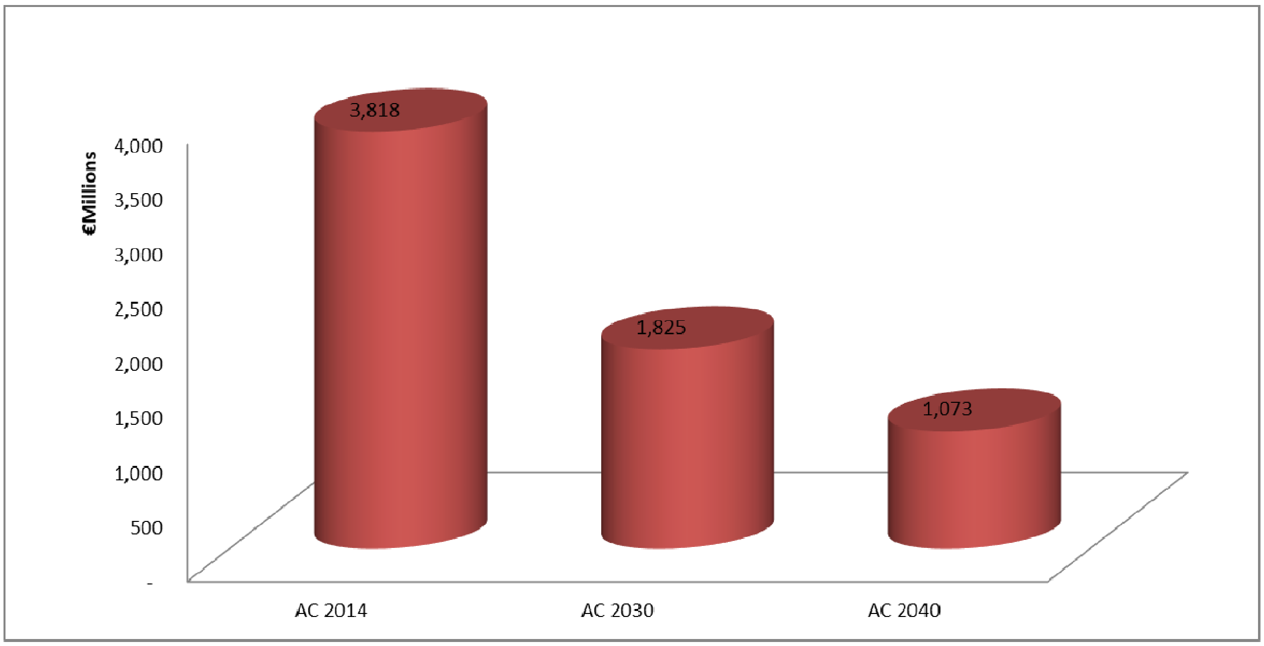
The calculated abatement costs presented in this report are converted into the 2014 Euro value to ensure comparability.

3.3.1 Abatement Costs of Air Emissions

BAU Abatement Costs of Air Emissios

Abatement costs for eight major types of air emissions are estimated using real data on energy consumption. The abatement cost for the air emissions in 2014 is EUR 3.82 billion. The number should be understood as the external costs that shipping activities burden on the environment, see Figure 38.

Figure 38: Total abatement cost of air emissions BAU in 2014, 2030 and 2040 (in million Euro)



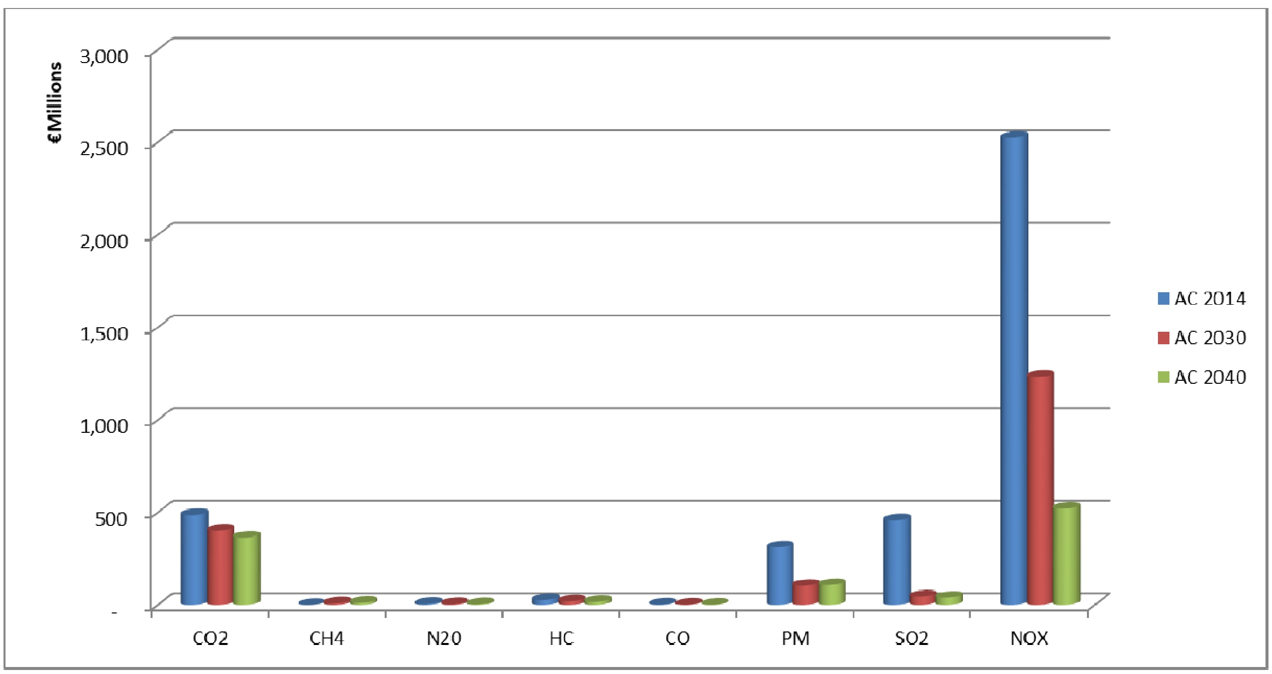
Taking into account the improvement of technology, environmental protection regulation and updated shipping management, there is an estimated reduction of 109.2% of air emission between 2030 and 2014 and 70% between 2040 and 2030 in the BAU. The abatement costs of air emissions in 2030 and 2040 are predicted respectively of EUR 1.83 and EUR 1.07 billion (Figure 38, in 2014 value).

Table 20: Share of Abatement cost of air emissions in BAU for different ship types (%)

Ship types	Cost share BAU 2014	Cost share BAU 2030	Cost share BAU 2040
Container ship	16.5%	17.4%	17.3%
General Cargo ship	10.9%	9.8%	9.0%
Bulk Cargo Ship	8.2%	8.0%	7.5%
RoRo ship	7.6%	7.2%	6.9%
RoPax Ship	25.6%	21.5%	20.5%
Vehicle Carrier	1.9%	2.1%	2.2%
Refrigerated Cargo ship	1.6%	1.3%	1.1%
Cruise ship	3.2%	3.3%	3.3%
Oil Tanker	7.3%	9.1%	10.2%
Product Tanker	3.1%	3.6%	3.7%
Chemical Tanker	13.1%	15.4%	16.3%
LNG Tanker	0.1%	0.1%	0.1%
LPG Tanker	1.1%	1.4%	1.7%
Total estimated costs (€ billion, 2014 value)	***3.82***	***1.82***	***1.07***

RoPax Ships are the top polluter with the AC share of over 20 % of all time (Table 20). The cost share of this type of ship is slightly reduced in 2030 and 2040 but it is still a domintant polluter. Other polluters with AC share of over 10 % include Container ships, Chemical tankers and General cargo ships.

Figure 39: Abatement Costs of typical types of air emission for BAU 2014, 2030 and 2040 (EUR million)



The AC of NO_x, CO_2, PM, SO_2 represent a majority of abatement costs of emission made by shipping. NOX emission created the largest cost share. In 2014 the AC of only NOx made by shipping is EUR 2.5 billion, accounted for 66 % of total AC for all eight types of emissions in the study (Figure 39).

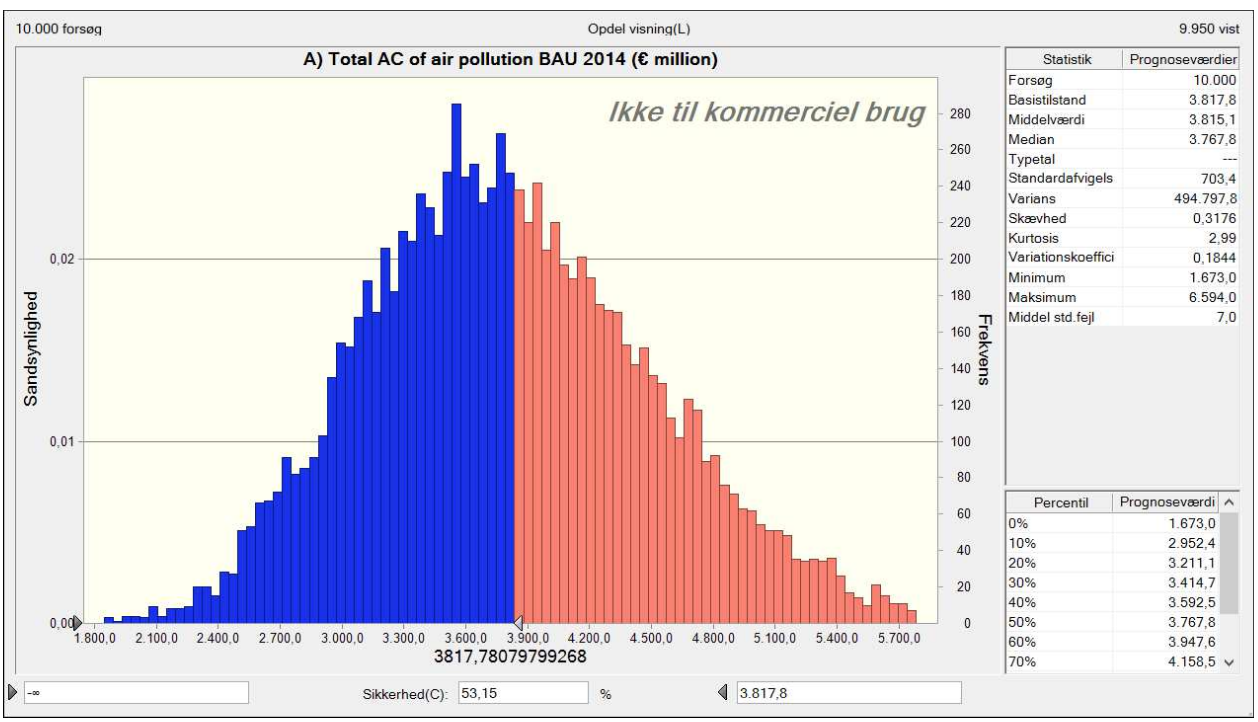
Sensitivity analysis of abatement costs of BAU for air emissions

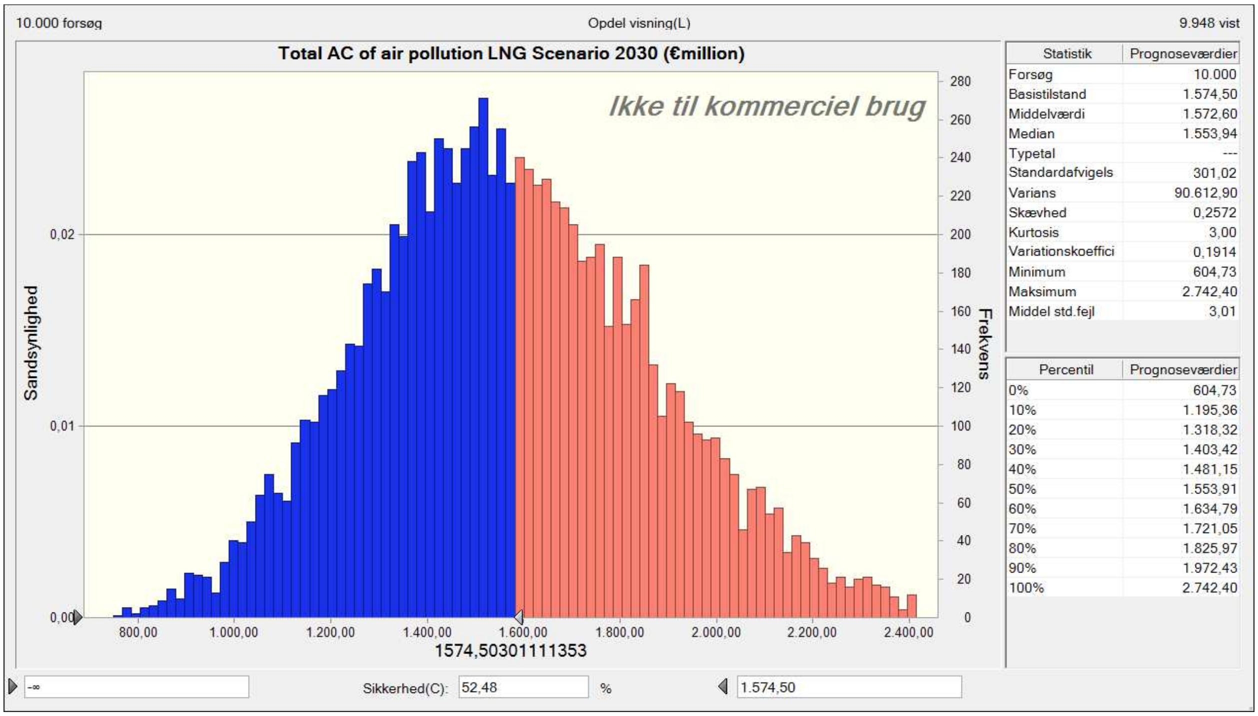
The total abatement costs calculated in the previous section are the mean values, which are calculated at average value of shadow price and average value of pollution level. The shadow prices are synthesized from published studies that were carried out for different locations and applying different methods. We assume that the shadow prices follow a normal distribution with means and standard deviations; they are reported in Table 2.The uncertainties of air mission levels are difficult to obtain so we rely on the expert opinion to obtain the range of the uncertainty level. Pollution levels are assumed to have uniform distributions with max and min values measured as percent of change in average volume.

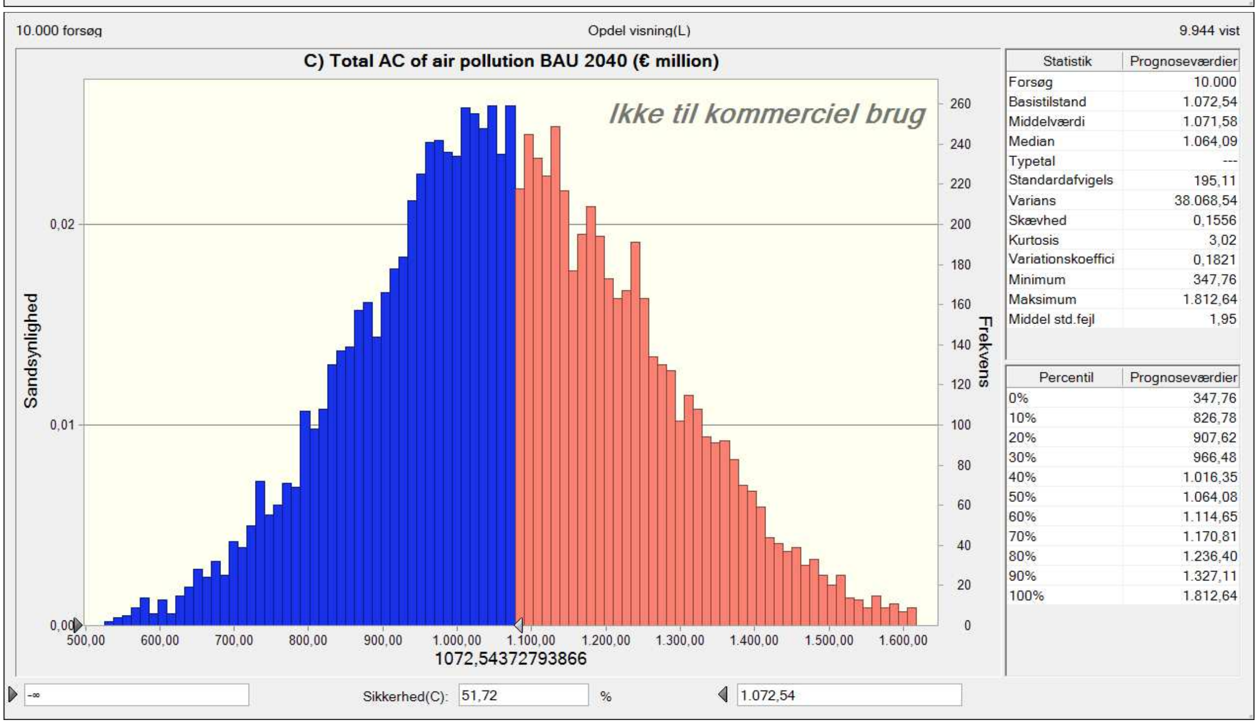
Based on the assumption of shadow prices and amount of emissions distributed we run simulations for all emission elements. Individual values of shadow price and emissions level are drawn from the assumed distribution. Then, the individual AC is calculated by multiplying the individual price and amount of emissions. There were 10,000 runs for each emission and the total AC of all emissions are summed up for each run. Total AC is therefore a distribution of values instead of a point value. Total abatement costs for BAU with accounting for uncertainties in the shadow prices and emissions levels are presented in Figure 40. The Figures present the distribution of the costs for BAU 2014, 2030 and 2040.

Figure 40a,b,c show a cumulative probability of over 51 % for the total costs are equal or higher to the total costs calculated at the mean values. More specifically, the figures provide that with a cumulative probability of 53 % the total AC of BAU 2014 is 3.82 EUR billion or higher, 52 % probability for the AC of BAU 2030 is from EUR 1.57 billion, and 51% probability the AC of BAU 2040 from 1.07 EUR billion.

Figure 40: The distribution of total abatement costs of air emissions of BAU







The tables on the right side of Figure 40 present the statitistics of total AC with uncertainties. It presents the maximium, minimium and other statistics of the AC distribution. In addition, the lower-right side table of the figures also present the ACs according to percentage of certainty levels. For instance, there is a 100 % probability e.g. 0% uncertainty that the total AC of BAU 2014 is at EUR 1,673 million, EUR 604 million for BAU 2030 and EUR 348 million for BAU 2040. Similiarly, with a 90 % certainty level or 90 % probability that the total AC of BAU in 2014, 2030 and 2040 are EUR 2.95 billion, EUR 1.20 billion, and EUR 0.83 billion. The higher probability level (certainty) the lower cost value.

Abatement Costs of NECA/NoNECA Scenario

NECA aims to reduce emissions of NOX as old vessels are replaced by new ones after 2021. In this scenario, new vessels from 2021 will follow the Tier III NOX emission regulations. The *NECA/NoNECA scenario* will impact mainly only the NOX emission.

Figure 41: Total abatement costs of NOx Emission of NECA/NoNECA scenario in 2030 and 2040 (2014 value)

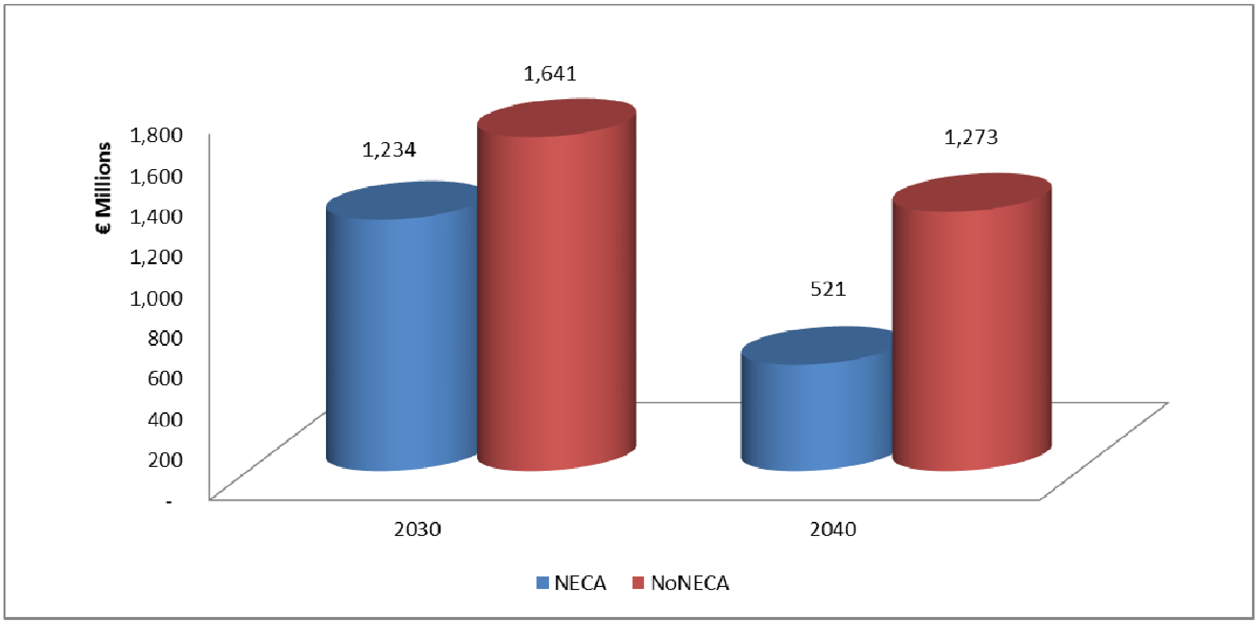
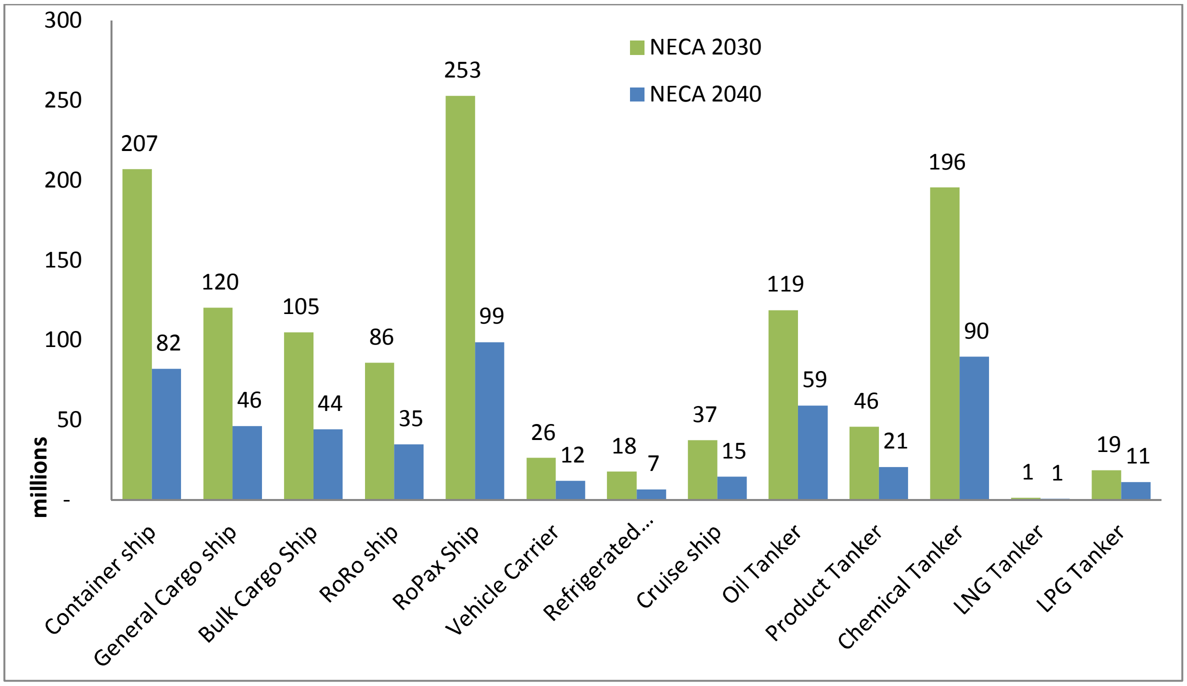


Figure 41 presents AC of NO_X emitted by shipping in the Baltic Sea in 2030 and 2040 for the case of NECA regulation and without NECA regulation. Notice that the NECA regulation has been considered when constructing BAU. Therefore the NOX level and AC of NOX in BAU are equal to the numbers of *NECA scenario*. To highlight the single effect of a NECA in the Baltic Sea the *NoNECA scenario* was calculated for comparison reasons.

It is estimated that the NECA regulations will reduce the AC of NOX by 25 % in 2030 and 59 % in 2040. The AC of NOX will be EUR 1,234 million in 2030 and EUR 521 million in 2040.

Figure 42: Abatement costs of NOX emitted by ship types for NECA/NoNECA scenario (EUR million)



Container ships, RoPax ships and chemical ships have the largest cost share of AC of NOX, each accounts for over 15 % of total costs. Table 21 Impacts of NECA regulations on abatement costs of ship types, compared to NoNECA presents the AC of NOX estimated for the *NECA scenario* in 2030 and 2040 for the different ship types.

Table 21 Impacts of NECA regulations on abatement costs of ship types, compared to NoNECA

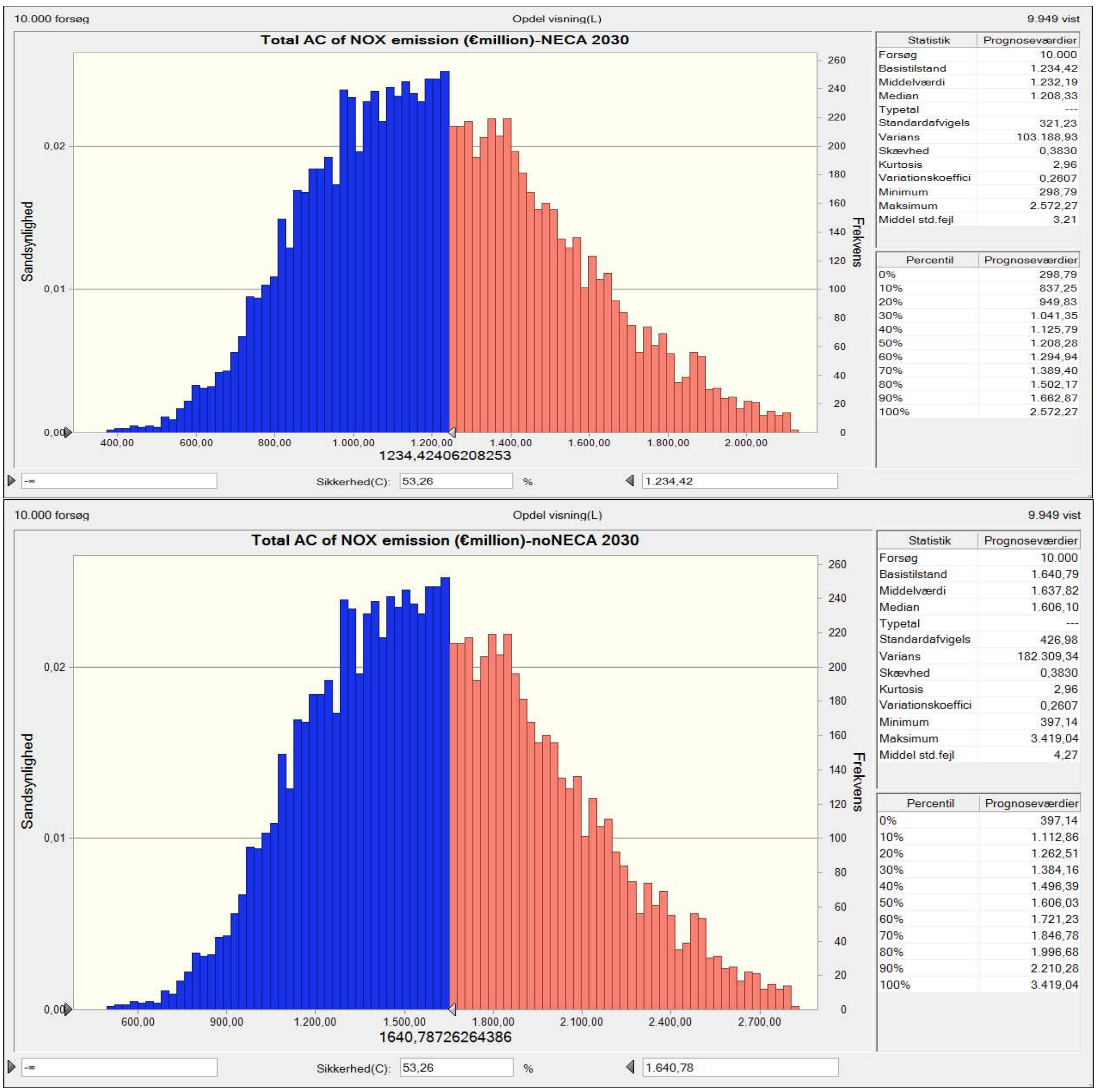
Ship types	NECA 2030	NECA 2040
Container ship	-26.4 %	-62.3 %
Chemical Tanker	-25.4 %	-60.3 %
Refrigerated Cargo ship	-25.4 %	-60.0 %
Product Tanker	-25.3 %	-60.7 %
Cruise ship	-25.3 %	-61.6 %
General Cargo ship	-25.2 %	-60.7 %
Bulk Cargo Ship	-25.1 %	-59.3 %
Oil Tanker	-24.8 %	-57.8 %
RoRo ship	-23.8 %	-56.8 %
Vehicle Carrier	-23.6 %	-56.1 %
RoPax Ship	-23.4 %	-55.4 %
LPG Tanker	-20.3 %	-46.6 %
LNG Tanker	-20.2 %	-46.7 %
Average change	***-24.8 %***	***-59.0 %***

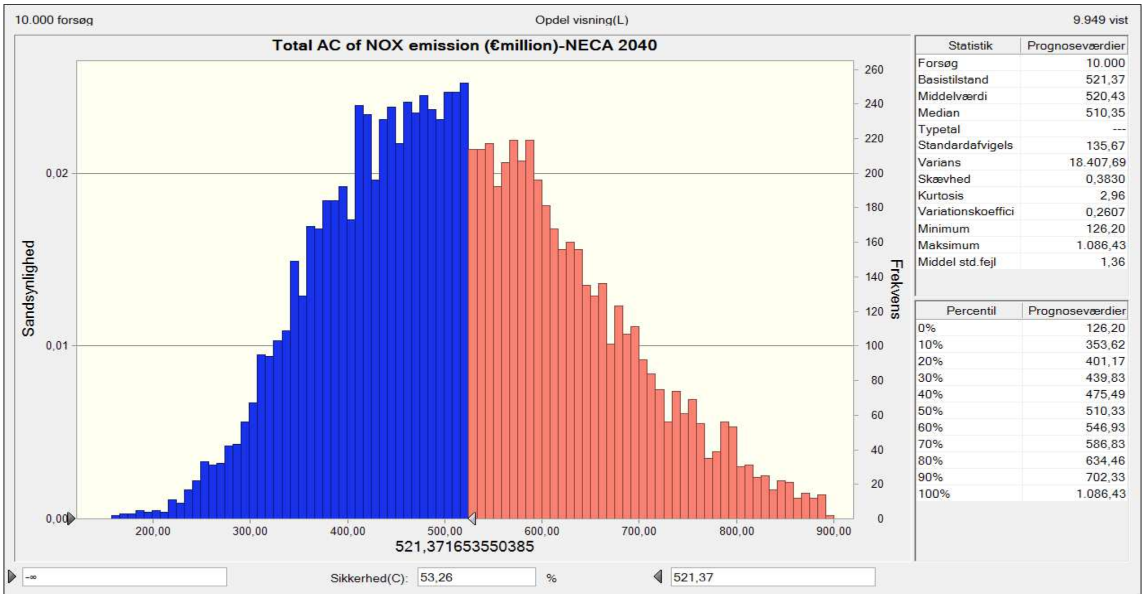
All ship types are impacted similarly by NECA regulations in terms of abatement costs of emissions (Table 21). On average, the NECA regulations will deduct 24.8 % of emission AC by 2030 and 59 % by 2040, compared to *NoNECA scenario*. Table 21 details the percent of reducing AC of emission between NECA and Non NECA implication for different ship types.

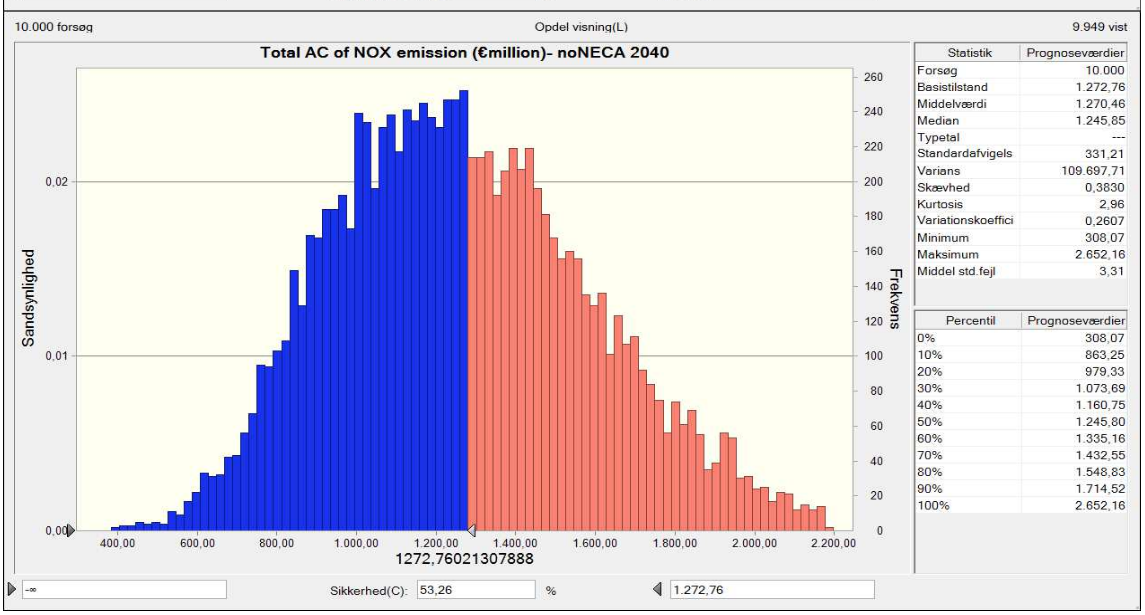
NECA Scenario with Uncertainties

The total costs estimated for *NECA scenarios* with accounting for the uncertainties of shadow prices and level of emissions are presented in Figure 43. The interpretation of the results is presented below.

Figure 43: Abatement Cost of NECA Scenario with uncertainty







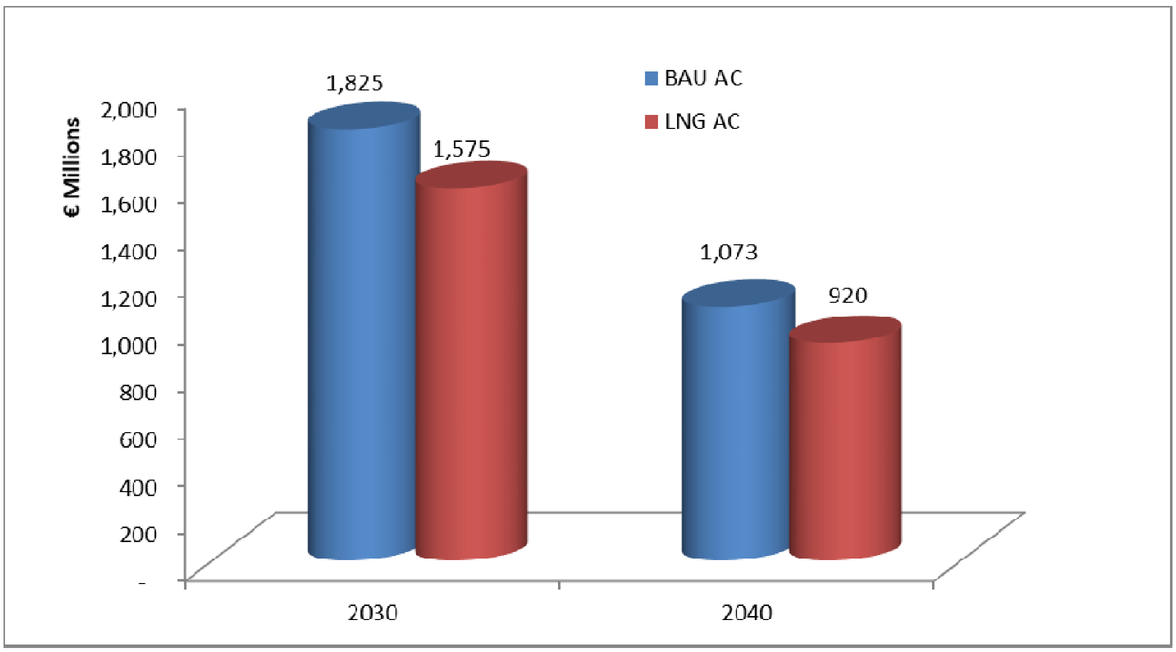
The total AC of the *noNECA scenarios* follows a normal distribution. With a certainty level of 90% the total AC of NECA 2030 and 2040 are EUR 837 million and EUR 354 million, respectively. Similarly, the AC of NoNECA 2030 and 2040 under a 90 % level of certainty are EUR 1,113 million and EUR 863 million, respectively. In other words, under a 90 % certainty level, *NECA scenario* would contribute to a reduction of 25 % and 59 % of abatement costs of NOX emissions from shipping in the Baltic Sea in 2030 and 2040, respectively.

Abatement Costs for the LNG scenario

Using Liquefied Natural Gas (LNG) as fuel in ships lowers emissions of sulphur dioxide (SO2), particles and nitrogen oxide (NOX) to air compared to operations on marine gasoil or heavy fuel oil. A negative effect is a slip of methane (CH4) from the engines, which contributes to atmospheric warming. A Directive (Directive 2014/94/EU) from the EU on the deployment of alternative fuels infrastructure points out LNG as an attractive marine fuel for ships sailing in the emission control areas. The Directive states that a core network of refuelling points for LNG at maritime ports should be available at least by the end of 2025 (European Union, 2014).

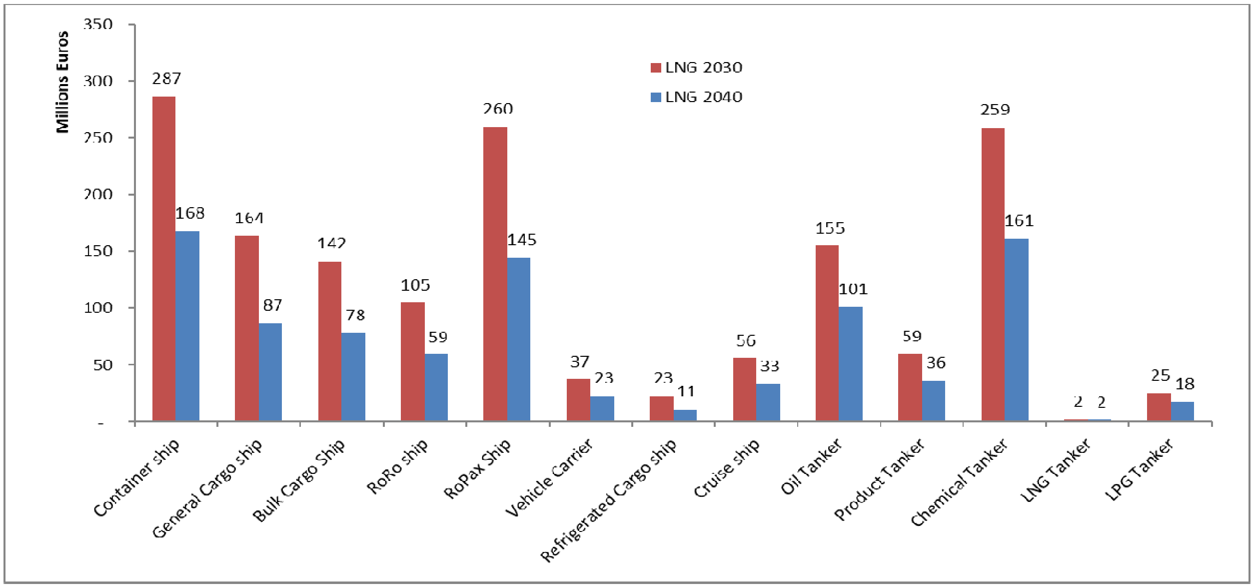
Figure 44 presents the calculated results of AC for the *LNG scenario* in 2030 and 2040. The values of BAU are also included for comparison. The AC of emission if the *LNG scenario* implemented is EUR 1.58 billion in 2030, which is 13.7 % lower than AC of BAU in 2030. The cost in 2040 is EUR 0.92 billion and 14.2 % lower than the BAU in 2040.

Figure 44: Abatement costs of air emissions: LNG scenarios and BAU (2014 value, EUR million)



The detail ACs for ship types according to *LNG scenario* are presented in Figure 45. RoPax ship, Container ships, Chemical tankers, general cargo ships and oil tankers account for the majority of AC in the *LNG scenario*. These ship types represent over 80 % of total cost in 2030 as well as 2040.

Figure 45: Abatement costs of air emission in LNG scenario for different ship types (2014 value, EUR million)



The LNG regulations impact mostly RoPax and RoRo ships in term of AC reduction. The AC of air emission from the two ship types will be reduced by 33.7 % in 2030 and over 34.2 % in 2040 for RoPax ship, and 19.4% in 2030 and 20.9% in 2040 for RoRo ship. Overal, LNG regulation will deduct abatement cost at 13.7% in 2030 and 14.2% in 2040, compared to BAU situation. Table 22 presents the impacts of *LNG scenario* on AC deduction for ship types compared to BAU.

Table 22 Impacts of LNG regulations on AC of shipping (percent of AC deduction, compared to BAU)

Ship types	LNG 2030	LNG 2040
Container ship	-9.4%	-9.6%
General Cargo ship	-8.4%	-10.5%
Bulk Cargo Ship	-2.8%	-3.4%
RoRo ship	-19.4%	-20.9%
RoPax Ship	-33.7%	-34.2%
Vehicle Carrier	-2.9%	-3.1%
Refrigerated Cargo ship	-5.4%	-6.7%
Cruise ship	-6.1%	-6.1%
Oil Tanker	-6.5%	-7.3%
Product Tanker	-8.3%	-9.2%
Chemical Tanker	-7.5%	-8.0%
LNG Tanker	-2.8%	-3.1%
LPG Tanker	-3.7%	-4.0%
Total reduction	***-13.7%***	***-14.2%***

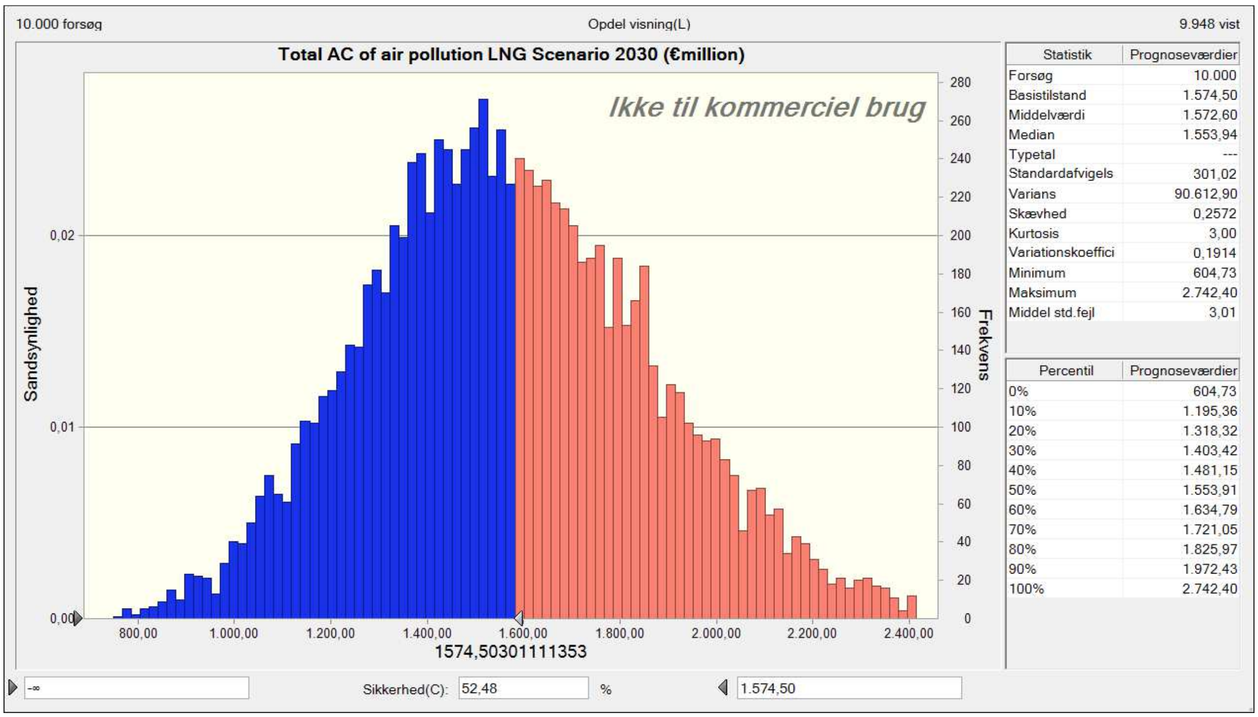
In summary, the shipping industry in Baltic Sea imposed an abatement cost of EUR 3.82 billion in 2014 due to externalities from air emissions. This cost will be reduced by 52.2 % by 2030 and 72% by 2040 due to technology improvements and the implementation of regional and global policies. RoPax ships, container ships, chemical tankers and general cargo ships are the major emitter in term of abatement cost.

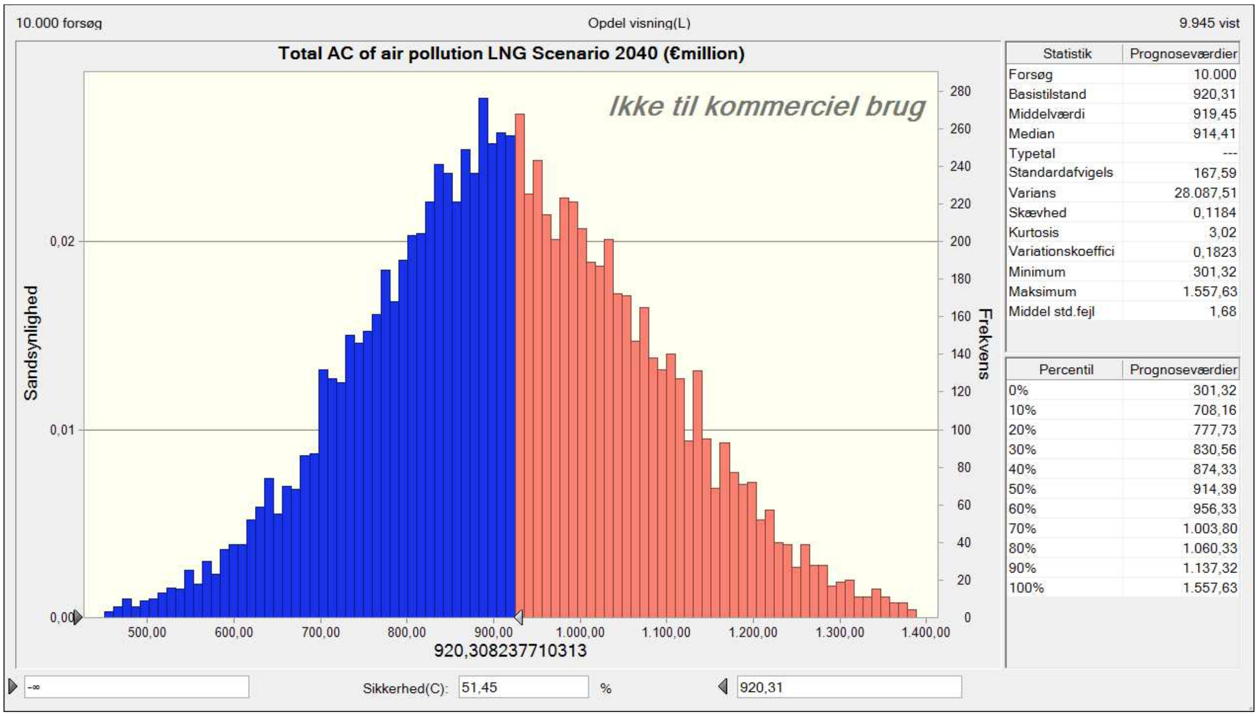
NECA regulation starting in 2021 will reduce the NOx abatement costs by 25 % in 2030 and 59 % in 2040, compared to a *NoNECA scenario*. The impacts of NECA on ship types are not significant different. LNG regulations will reduce around 13.7 % of total AC of air emission in 2030 and 14.2% in 2040 compared to BAU. RoPax and RoRo ship types are the most impacted in case of the *LNG scenario*.

LNG Scenario with Uncertainties

Total AC of *LNG scenarios* taking into account the uncertainties of input data are presented in Figure 46. The Figure shows an average AC of EUR 1.57 billion in 2030 and EUR 0.92 billion in 2040 for *LNG scenario* with a certain level of 52 % and 51 %.

Figure 46: Total Abatement Cost of air emissions in LNG Scenario with Uncertainties





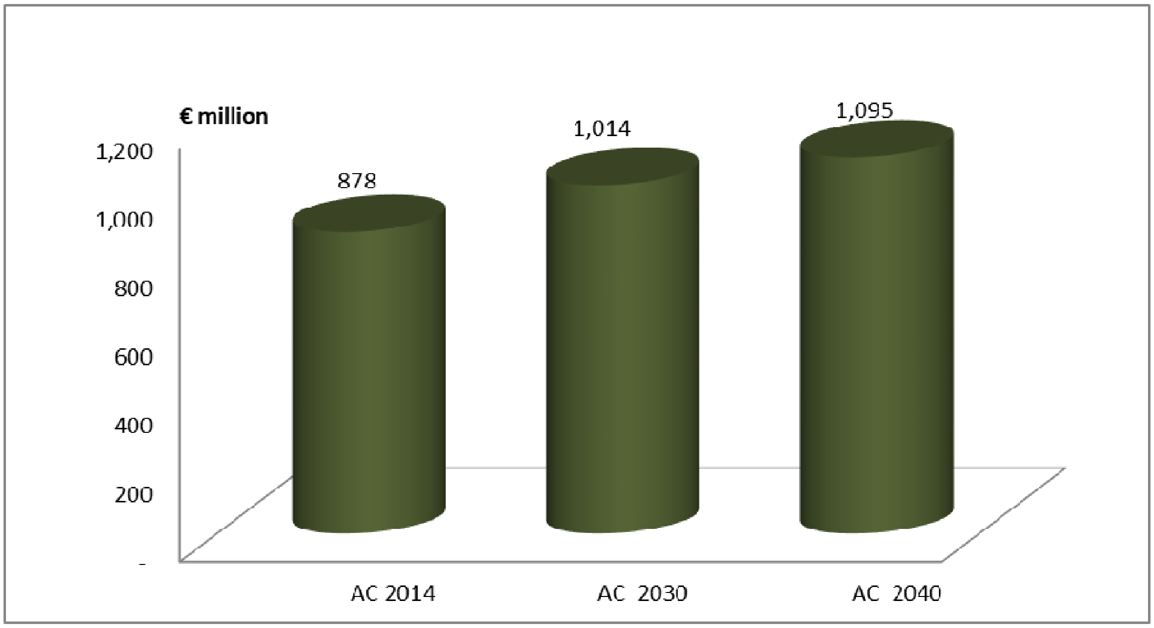
The distribition of AC for *LNG scenario* is nornally distributed. Under a certain level of 90 % the total AC of *LNG scenario* are EUR 1.20 billion in 2030 and EUR 0.71 billion in 2040.

3.3.2 Abatement Costs of Water Pollution

Abatement costs of water pollution for BAU

The abatement costs of water contaminants in 2014 is estimated to be EUR 878 million. The cost will increase by 15.5 % in 2030 and 24.8 % in 2040 in the BAU (Figure 47). Although marginal AC of water contaminants are much higher than those of air emissions but the pollution levels in water are much lower, the result is that the total AC of air emissions are nearly 5 times higher than AC of water contaminants.

Figure 47: Abatement cost of water pollution BAU in 2014, 2030 and 2040 (EUR million)



The ship types responsible for a major proportion of AC of water contaminants are bulk cargo, general cargo, oil tanker, chemical tanker and RoPax ship (Table 23). Each of these ship types account for over 12 % of the total AC cost. These ship types together represent over 75 % of the cost.

Table 23: Share of abatement cost of Water Pollution for ship types (%)

Ship types	2014	2030	2040
Bulk Cargo Ship	19.31 %	17.81 %	17.04 %
General Cargo ship	17.38 %	15.10 %	13.98 %
Oil Tanker	13.96 %	15.12 %	15.91 %
Chemical Tanker	13.66 %	14.62 %	15.34 %
RoPax Ship	12.56 %	12.83 %	12.97 %
Container ship	8.21 %	9.20 %	9.30 %
Product Tanker	4.33 %	4.59 %	4.81 %
Cruise ship	3.67 %	3.78 %	3.76 %
RoRo ship	3.51 %	3.47 %	3.43 %
Refrigerated Cargo ship	1.27 %	1.12 %	1.04 %
Vehicle Carrier	1.05 %	1.18 %	1.17 %
LPG Tanker	0.84%	0.91%	0.96%
LNG Tanker	0.26%	0.28%	0.30%
Total abatement cost (EUR million)	**877.94**	**1,014.44**	**1,095.32**

Heavy metals such as copper, zinc and lead are normal constituents of marine and estuarine environments. However, when additional quantities are introduced from industrial wastes or sewage they enter the biogeochemical cycle and, as a result of being potentially toxic, may interfere with the ecology of a particular environment (Bryan, 1971). These pollutants tend to accumulate in the bottom sediments, making ecosystems such as seaports having highly contaminated sediments and have high potential effects on human health risks (via the food chain) (Ansari et al. 2004).

Copper from shipping makes up a large proportion of impacts on the ecosystem in terms of abatement cost. This metal share is over 85 % of total abatement cost AC of water pollution from shipping (Table 24). About 99 % of total polluted level of copper released to the sea is from antifouling activities.

Table 24: Abatement cost of water contaminants in BAU (EUR million, 2014 value)

Ship types	BAU 2014	BAU 2030	BAU 2040
Copper	769.76	877.79	944.14
Photphorius	81.55	97.04	106.84
Zinc	15.59	19.80	21.63
Nitor	9.44	12.54	13.98
Niken	0.70	3.67	4.42
Dibromochloromethane	0.37	0.43	0.48
Cobalt	0.35	2.87	3.50
Naphthalene	0.07	0.06	0.06
Asernic	0.04	0.05	0.05
Lead	0.03	0.09	0.10
Mercury	0.02	0.04	0.05
Cadmium	0.01	0.02	0.02
Pyrene	0.0051	0.0432	0.0526
Total cost	877.94	1014.44	1095.32

Figure 48: Share of copper by ship type polluting the Baltic Sea by antifouling activities

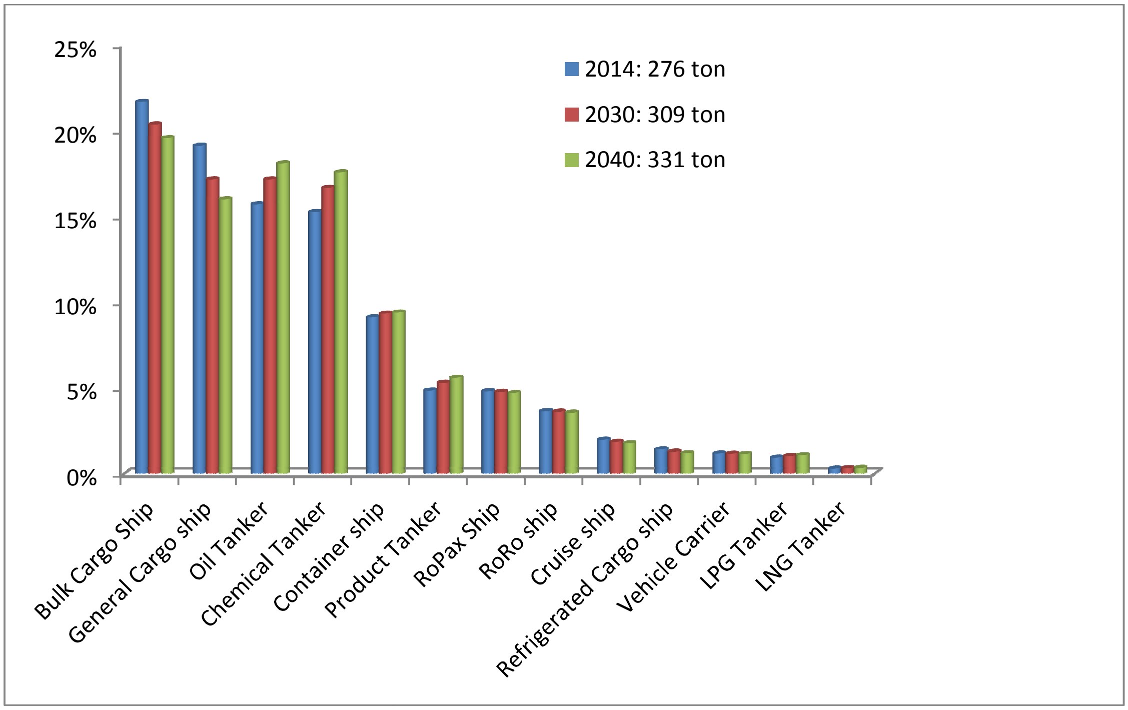


Figure 48 presents the proportion of copper contaminants made by antifouling activities. The total amount of copper contaminants to the Baltic Sea from antifouling is about 276 tonnes in 2014, 309 tonnes in 2030 and 331 tonnes in 2040. Bulk cargo, general cargo, oil tanker and chemical tankers are the ship types which make the highest percentage of copper releases to the sea by antifouling.

The most toxic compounds released to sea water from shipping are Mercury, Dibromochloromethane and Naphthalene, as indicated by high shadow prices. However, the pollution levels of these compounds are small, resulting in low abatement costs. The abatement costs of these compounds represent less than 0.5% of total abatement costs of water pollutions).

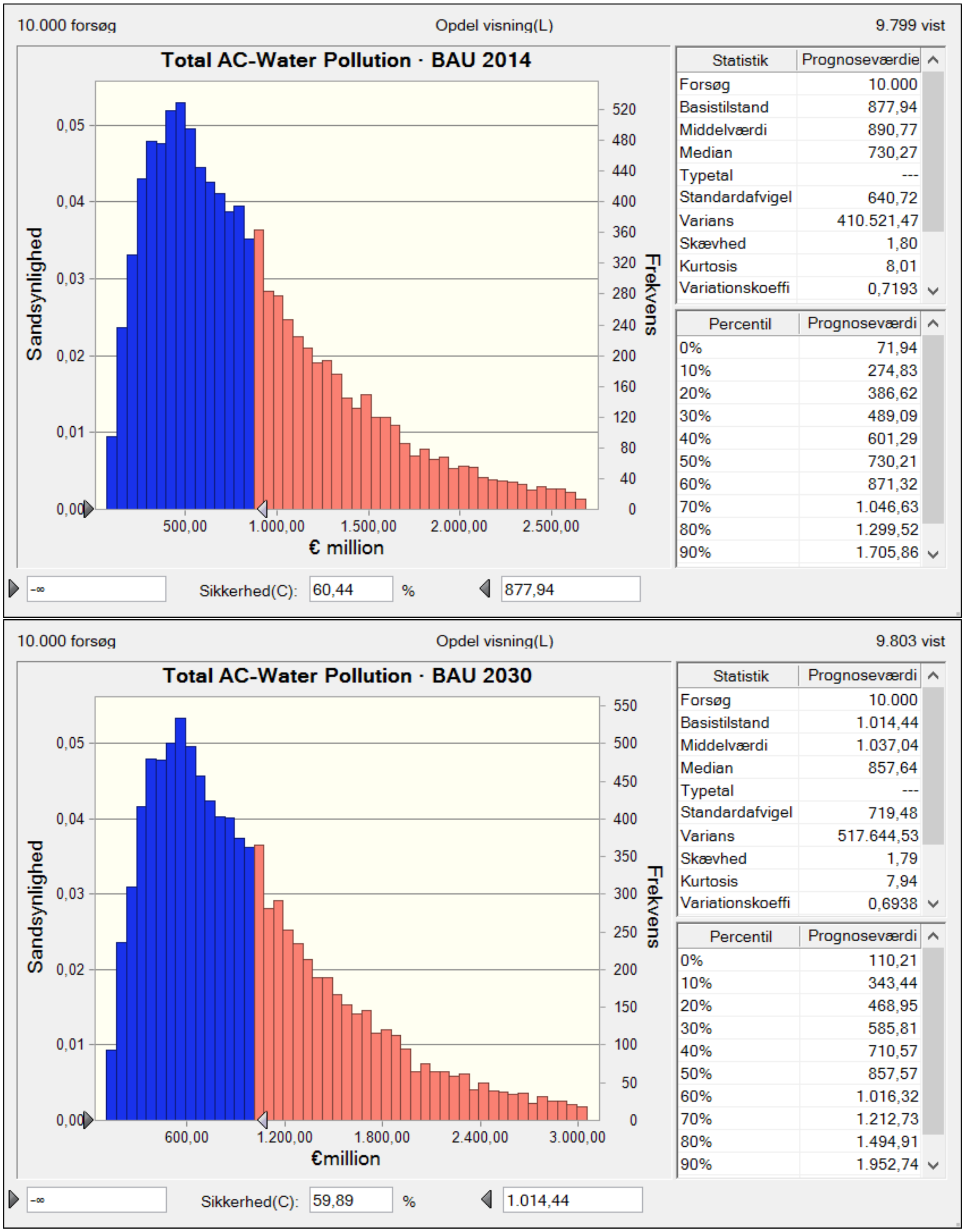
Abatement Cost with Uncertainties for BAU

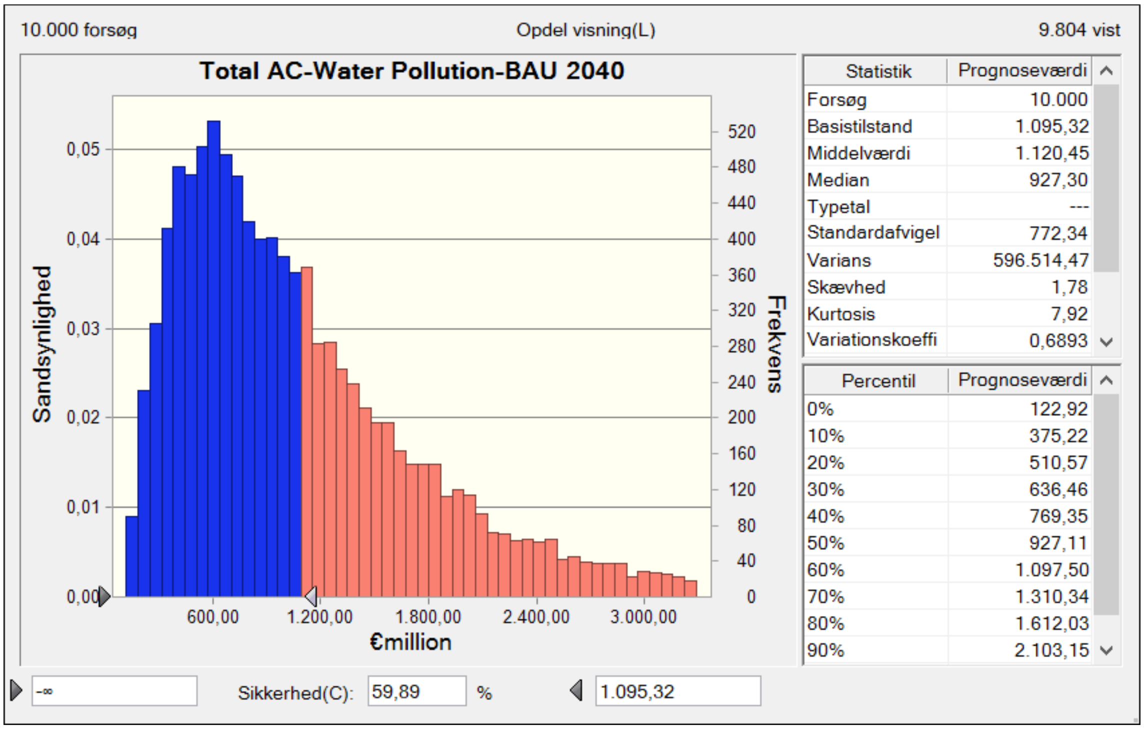
The total costs of BAU and scenarios are calculated again, including the uncertainties in the input data of shadow prices and in the pollution amounts. It was assumed that shadow prices have standard normal distributions with a mean value according to Table 3 and a standard deviation of 0.2. Because the shadow prices of water pollutants are rarely documented we cannot collect a better value of standard deviation.

The amount of contaminants in shipping discharges are calculated as the discharge volume multiplied with the average concentration of the contaminants in the discharged water. The concentrations vary both in term of average value and variance (see Table 3). The variance in contaminant concentration was calculated from the collected data on contaminant concentration in shipping discharged (Eriksson et al. 2015).

We assume that the concentration of contaminants in wastewater made by ships follow a Gamma distribution. The Gamma distribution is continuous, applied widely in a range of physical quantities, and is related to other distributions: lognormal, exponential, Pascal, Erlang, Poisson, and chi-squared. It is used in meteorological processes to represent pollutant concentrations and precipitation quantities (Kirchner et al., 2000). In addition, the Gamma distributions are appropriate distributions for data with only positive values. The distribution has three parameters including location, shape (alpha) and scale (beta). The location parameters are set to be zero while shape and scale parameters of each contaminants are calculated basing on average and variance values of the concentrations.

Figure 49: Total Abatement cost of water pollution with uncertainties



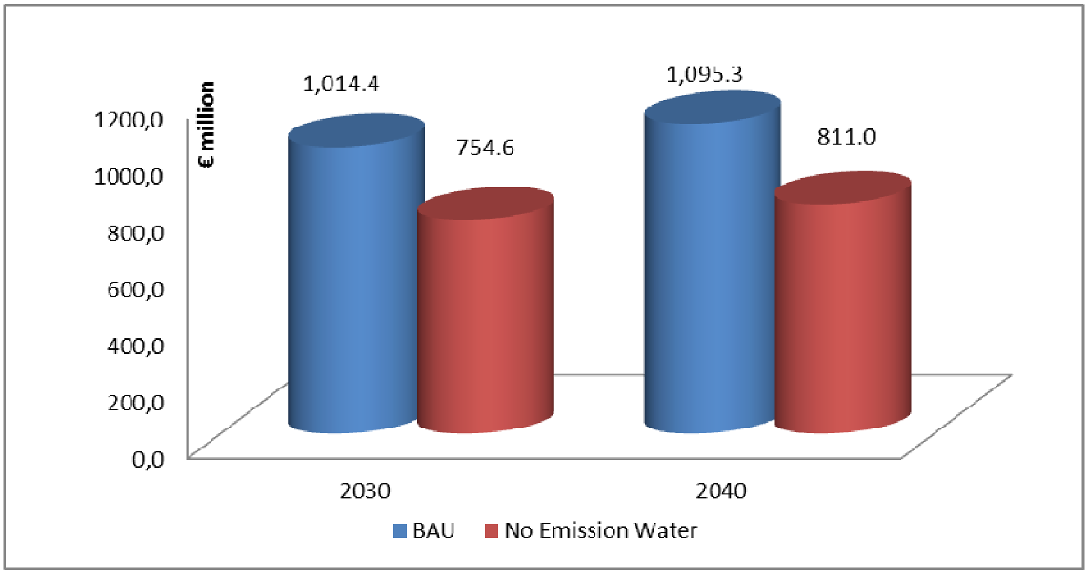


The simulation shows that the likelihood to obtain an average value of total AC for BAU for 2014 (EUR 878 million), 2030 (EUR 1,014 million) and 2040 (EUR 1,095 million) are around 60% as shown in Figure 49 above. The figure also shows the min and max value of the total AC for each year. The minimum total AC (i.e. the costs with 100% certainty) are EUR 72 million (in 2014), EUR 110 million (2030) and EUR 123 million (2040).

Abatement costs of Zero-Emissions to Water Scenario

Currently (2017) it is allowed to discharge untreated black water and ground food waste beyond 12 nautical miles off the nearest coast into the Baltic Sea. Greywater is not regulated by international law. The *zero-emission scenario* aims to investigate the changes in impact on the Baltic Sea from a number of regulations limiting emissions to water from shipping by revising MARPOL 73/78 Annex IV Sewage which prohibits discharging untreated black water from passenger ships (MARPOL 73/78, 2005).

Figure 50: Abatement cost of water pollution of Zero-Emissions to Water Scenario and BAU (EUR million)



The *Zero-Emissions to Water Scenario* will reduce the abatement cost by 26 % in 2030 as well as 2040, compared to AC of BAU (Figure 50). In the scenario the pollutions of RoPax ships change the most, so that the abatement cost for water pollution from this ship type will be reduced by about 90 % in 2030 and 2040, compared to AC of BAU (Table 25). Water pollutants from cruise ship, RoRo ship, and vehicle carrier are also changing significantly.

Table 25: Change of abatement cost of No Emission to Water Scenario Compared to BAU

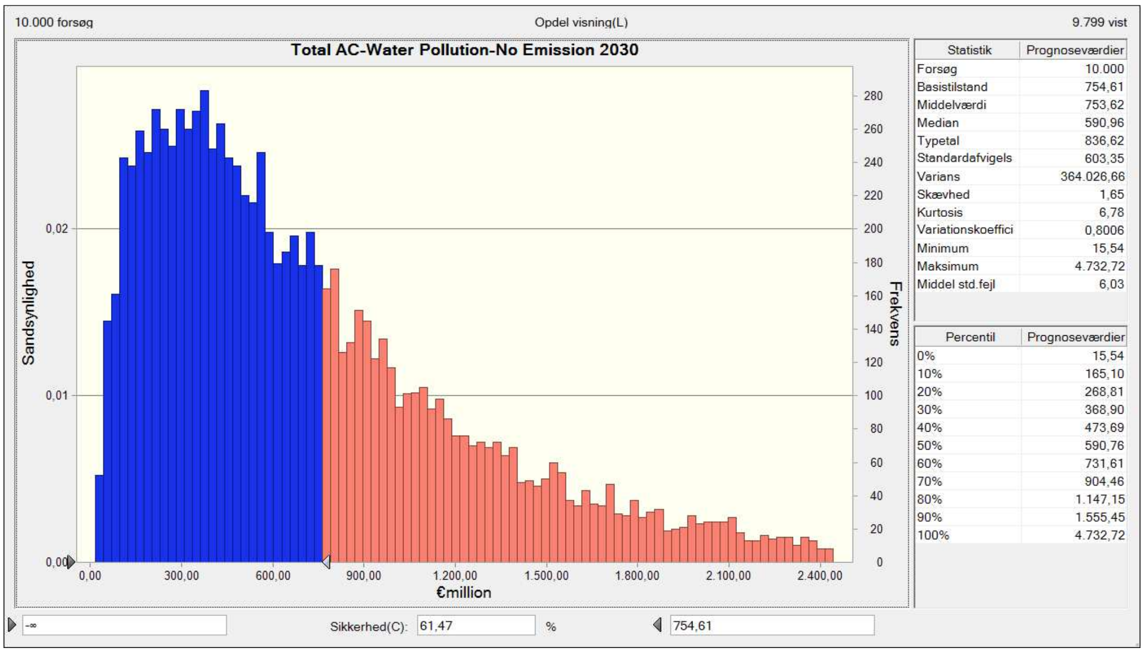
Ship types	Change in 2030	Change in 2040
Container ship	-23.2 %	-23.9 %
General Cargo ship	-16.2 %	-16.2 %
Bulk Cargo Ship	-7.9 %	-8.0 %
RoRo ship	-54.9 %	-55.2 %
RoPax Ship	-89.9 %	-90.1 %
Vehicle Carrier	-29.9 %	-30.8 %
Refrigerated Cargo ship	-2.5 %	-2.6 %
Cruise ship	-60.5 %	-62.3 %
Oil Tanker	-10.3 %	-10.6 %
Product Tanker	-10.0 %	-10.1 %
Chemical Tanker	-10.0 %	-10.2 %
LNG Tanker	-3.3 %	-3.8 %
LPG Tanker	-3.6%	-4.0%
Average change	-25.6%	-26.0%

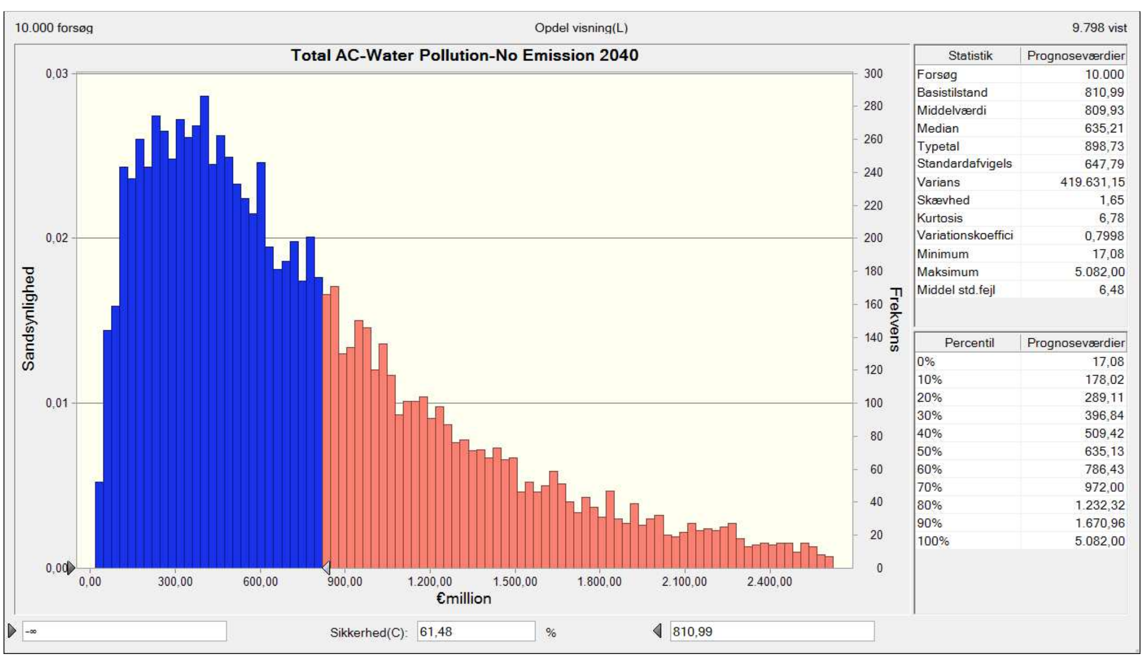
Some contaminants, such as Cobalt, Naphthalene, Pyrene and Phosphorus, will be reduced to zero by the years 2030 and 2040 when the scenario is completely implemented.

The Environemtal cost of Zero- Emission to Water Scenario with uncertainties

The results of the sensitivity analysis are provided in Figure 51. It shows that at a likelihood of 62 % the total AC for Zero-Emission scenario is EUR 754 million in 2030 and EUR 811 million in 2040.

Figure 51: Total AC of No Emission to Water with Uncertainties



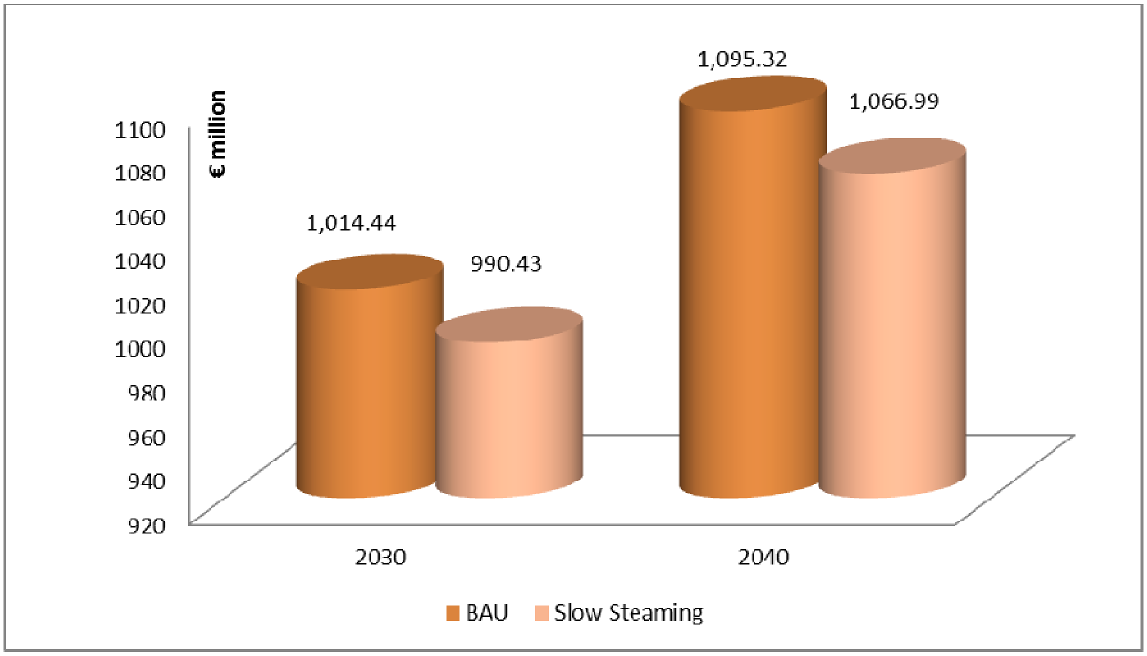


The minimum costs at 100 % uncertainty level are EUR 16 million and EUR 17 million in 2030 and 2040, respectively.

Abatement costs of Slow Steaming Scenario (SSS)

Slow steaming scenario aims to investigate changes in emissions to air, water and noise that come from a general reduction in vessel speed. In the scenario vessels will run 10 % slower than normal and the consequence is that more vessels are required in the transport system in order to perform the same transport work. The *Slow Steaming Scenario* results in reductions in fuel consumption and emissions to air but increase the emissions to water.

Figure 52: AC of water pollution of Slow Steaming Scenario and BAU (EUR million)



Total AC of water pollution in slow steaming scenario is EUR 990 million in 2030 and EUR 1,067 million in 2040 (Figure 52). Compared to BAU, *Slow Steaming Scenario* will reduce AC of water pollution insignificantly at only 2.4 % in 2030 and 2.6 % in 2040. Only RoPax ships and Cruiser ships have significantly reduced the abatement cost of water pollution. AC of other ship categories will increase slightly (Table 26).

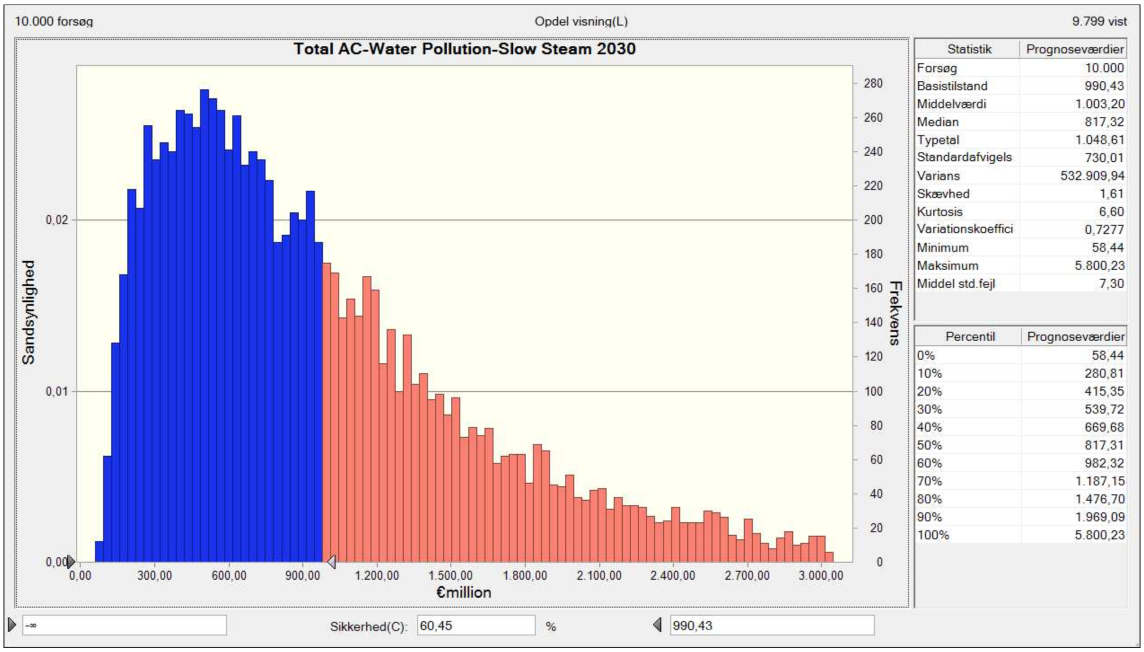
Table 26 Change of AC of Slow Steaming Scenario Compared to BAU

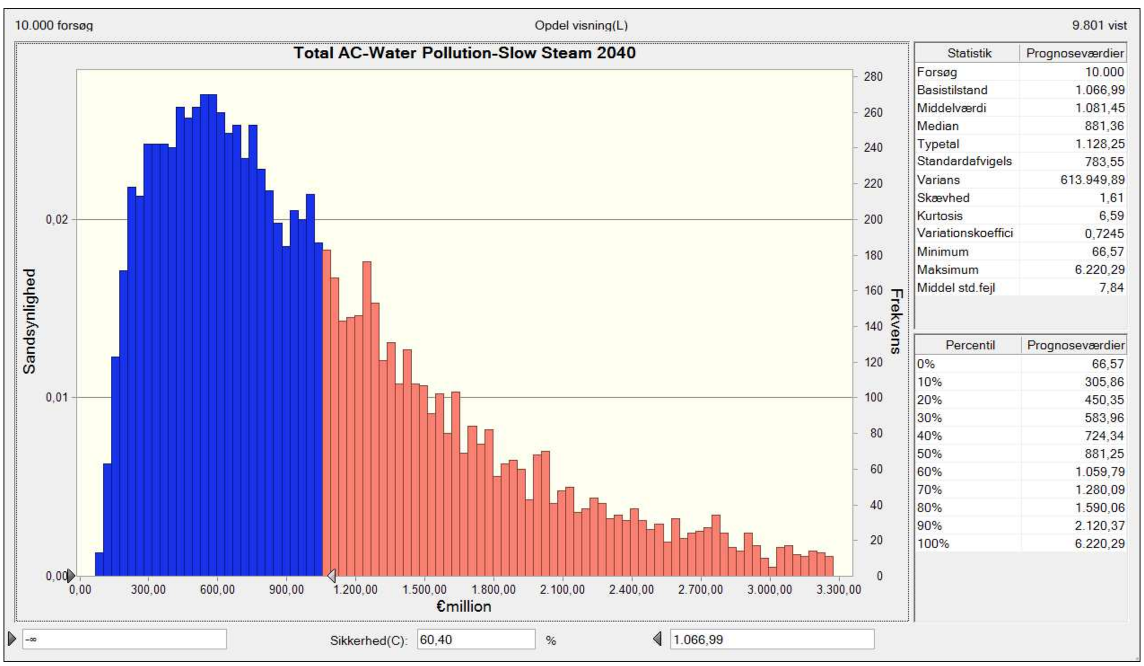
Ship types	Change in 2030	Change in 2040
Container ship	1.6 %	1.4 %
General Cargo ship	2.8 %	2.7 %
Bulk Cargo Ship	2.3 %	2.3 %
RoRo ship	1.5 %	1.2 %
RoPax Ship	-29.2 %	-29.6 %
Vehicle Carrier	0.2 %	-0.2 %
Refrigerated Cargo ship	2.2 %	2.2 %
Cruise ship	-12.4 %	-12.9 %
Oil Tanker	1.9 %	1.8 %
Product Tanker	1.9 %	1.8 %
Chemical Tanker	2.7 %	2.6 %
LNG Tanker	1.2 %	1.0 %
LPG Tanker	2.2 %	2.1 %
Average change	-2.4 %	-2.6 %

Total AC of Slow Steam Scenario with Uncertainties

The uncertainties in the input data for costs for *Slow Steam Scenario* is provided in Figure 53. The chance to obtain an average costs above EUR 990 million in 2030 and EUR 1,067 million in 2040 is about 60 %.

Figure 53: Total AC of Slow Steam Scenario with Uncertainties





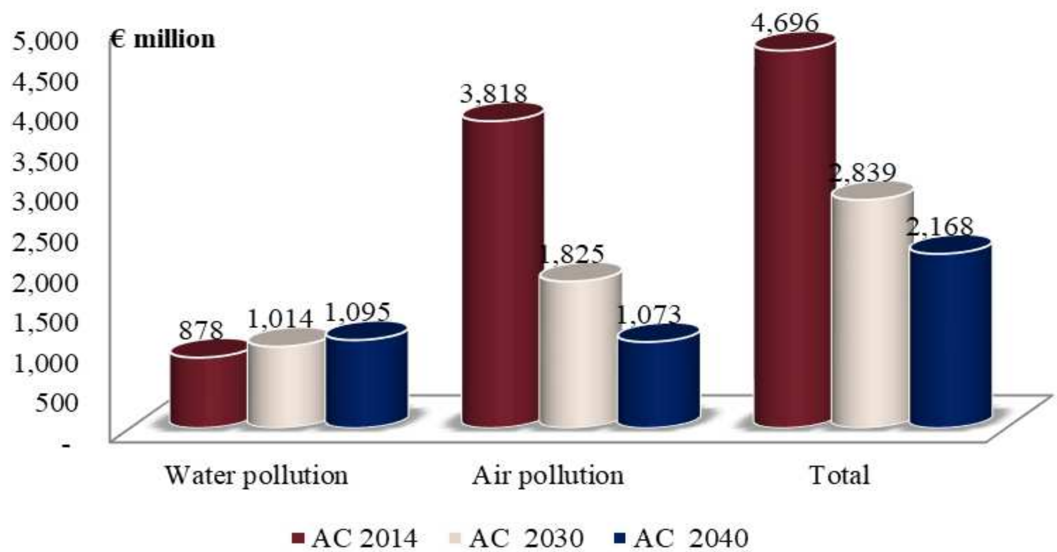
The minimum costs in *Slow Steam scenario* (i.e., costs with 100 % certainty level) are EUR 58 million in 2030 and EUR 67 million in 2040.

3.3.3 Summary of abatement costs of shipping in the Baltic

This section provides the abatement costs of water and air emissions made by shipping in Baltic Sea. The abatement costs are calculated by using shadow prices which is referred to as the marginal cost needed to improve one level of environmental quality (e.g., cost of reducing one tone of CO2). The shadow price is a equilibrium price where damage cost curve and abatement cost curve meet.

For BAU, the total abatement cost of both air emissions and water pollution caused by shipping in the Baltic Sea is EUR 4.70 billion in 2014 (Figure 54). The cost will reduce by 38 % in 2030 and 50 % in 2040 due to the technology improvement and environmental policy implementation included in the BAU. The reduction of total abatement costs is completely due to the reduction of air emissions' concentration. The cost of water pollution is increasing slightly in 2030 and 2040.

Figure 54: Summary of AC of Pollution from Shipping in Baltic Sea for the BAU (2014 value)



The AC cost share among ship types for the BAU are provided in Table 27. RoPax ships, container ships, chemical tankers, general cargo ships and bulk cargo ships are the main contributors of pollution in terms of abatement cost in the BAU.

Table 27. Total AC of water and air emissions from shipping in Baltic Sea for the BAU (2014 value)

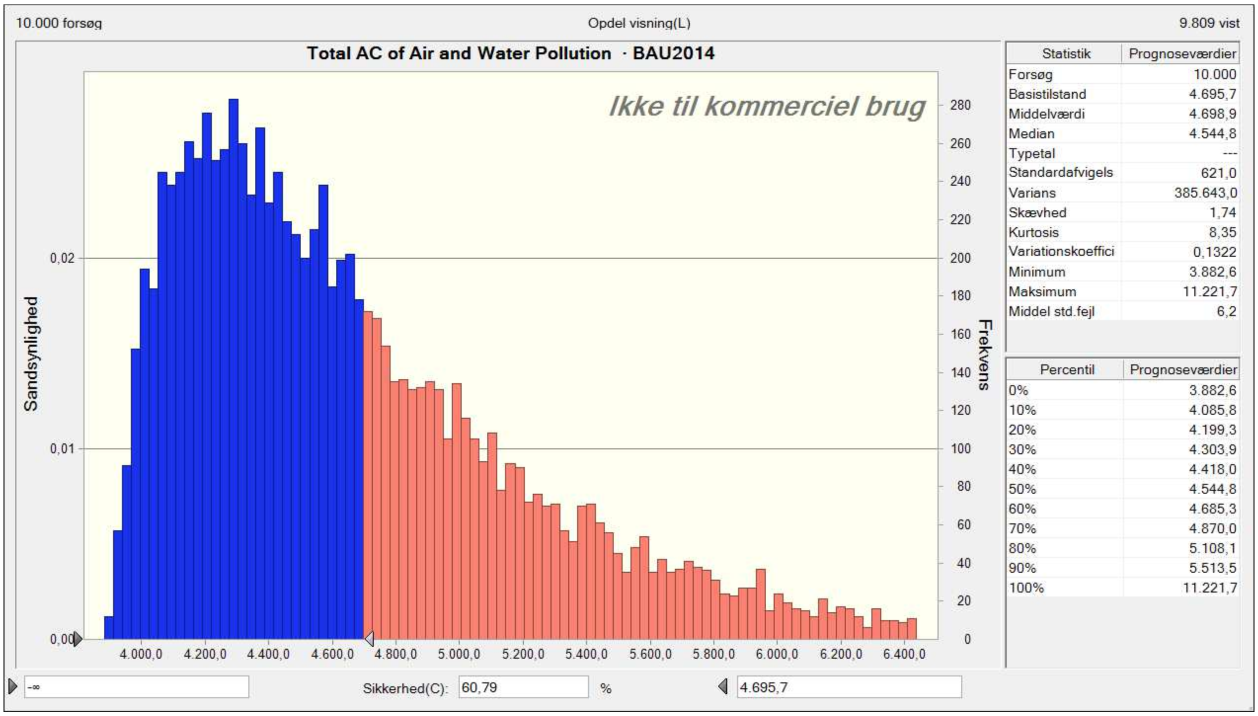
Ship types	2014		2030		2040	
	€ million	%	€ million	%	€ million	%
Container ship	700.99	14.9%	410.07	14.4%	287.55	13.3%
General Cargo	568.13	12.1%	331.90	11.7%	250.14	11.5%
Bulk Cargo Ship	483.33	10.3%	326.26	11.5%	267.49	12.3%
RoRo Ship	319.26	6.8%	165.74	5.8%	111.87	5.2%
RoPax Ship	1,088.69	23.2%	522.42	18.4%	361.69	16.7%
Vehicle Carrier	80.11	1.7%	50.29	1.8%	36.45	1.7%
Refrigerated Cargo	72.31	1.5%	35.61	1.3%	23.22	1.1%
Cruise ship	153.67	3.3%	97.79	3.4%	76.74	3.5%
Oil Tanker	401.80	8.6%	319.30	11.2%	283.08	13.1%
Product Tanker	155.43	3.3%	111.39	3.9%	92.33	4.3%
Chemical Tanker	618.65	13.2%	428.38	15.1%	343.36	15.8%
LNG Tanker	5.36	0.1%	4.88	0.2%	4.83	0.2%
LPG Tanker	47.91	1.0%	34.88	1.2%	29.04	1.3%
SUM	4,695.65	100%	2,838.91	100%	2,167.80	100%

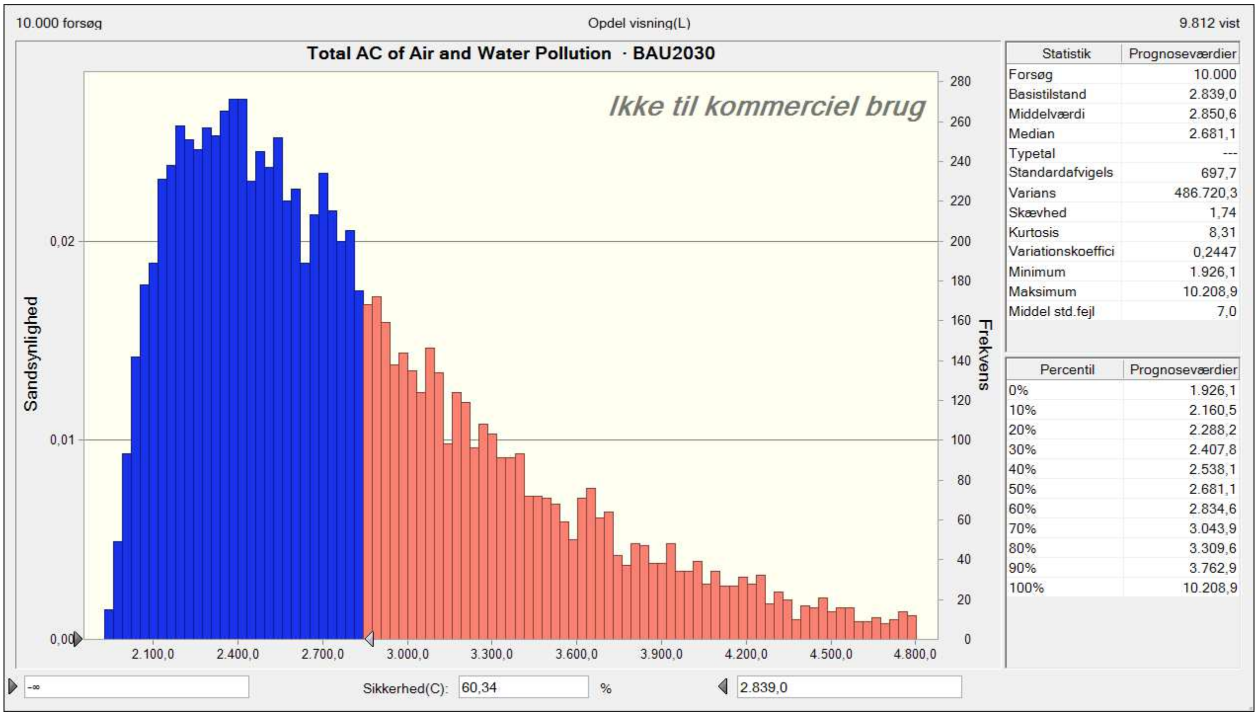
The abatement costs of the scenarios are also calculated using the results of future development in SHEBA D1.4 (see Fridell et al, 2016). ACs of air emissions for *NECA* and *LNG scenarios* are calculated. It indicates that the *NECA scenario* will deduct 25 % of AC cost in 2030 and 59 % in 2040 compared to a *NoNECA scenario* (based on changes of air emissions). *LNG scenario* will reduce total AC by about 13.7% and 14.2% in comparison with BAU 2030 as well as 2040, respectively.

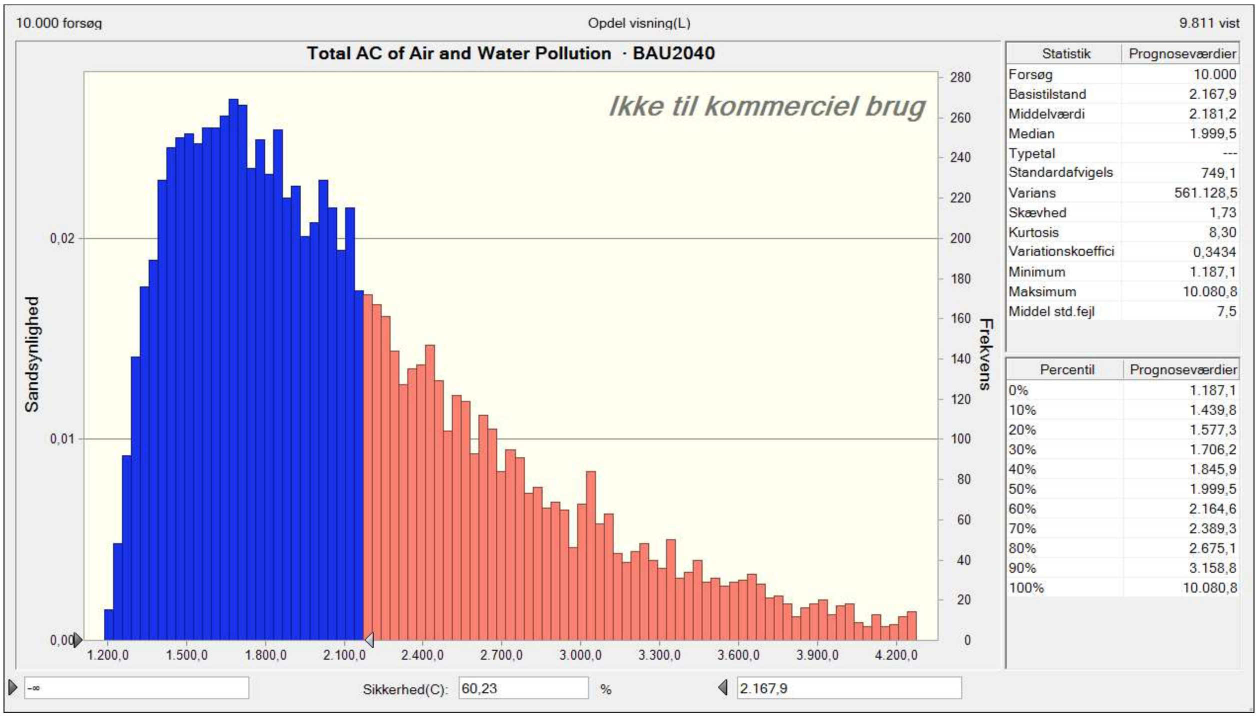
AC of water pollution for the *Zero-Emissions to Water* and the *Slow Steaming scenarios* are calculated. Compared to BAU, in the *Zero-Emissions to Water scenario* the total AC will be reduced with 25.6 and 26 % in 2030 and 2040 compared to BAU, respectively. In the *Slow Steaming scenario* the total AC will be reduced with only 2.4 % and 2.6 % compared to BAU in 2030 and 2040, respectively. The uncertainties in the total costs of air and water pollution are presented in

.

Figure 55: Total AC of Air and Water Pollution in BAU with Uncertainties







The distribution of AC of air emissions is normal while the distribution of AC of water pollution is more likely a gamma distribution, as the result from mixing distribution of price and pollution volumes. As a result the total costs of air emissions and water pollution is a mixed distribution and a skewed value of about 1.7. The probability of obtaining the average costs is around 60 %. The minimum total costs of air and water pollution are estimated at EUR 3.88 billion in 2014, EUR 1.92 billion in 2030 and EUR 1.19 billion in 2040.

4 Summary on costs of degradation

The Baltic Sea ecosystem is influenced by a number of different pressures originating from a variety of human activities, leading to changes in the Baltic Sea marine environment, its species and habitats, and impacting humans. This report, prepared in the BONUS SHEBA project, aims to analyse the costs of degradation and the impacts on human well being from shipping in the Baltic Sea. For the report, in addition to a stakeholder consultation exercise (see section 2.1), two main assessment approaches for costs of degradation are used: an analysis of ecosystem services (including in depth-case studies on specific presssures) (see section 2.2) and an estimation of abatement costs (see section 2.3). The ecosystem services assessment as well as the abatement cost estimation was based on available literature, statistics, and expert opinion and emission estimations in the BONUS SHEBA project.

Ecosystem services approach

For the analysis an assessment framework for shipping based on the DPSIR framework was applied (see section 1.1). The framework was developed to assess the linkages from the pressures of shipping in the Baltic Sea to its effects on ecosystem services and human well being. In the ecosystem services assessment of costs and degradation (see section 3.2), the main pressures from shipping were included: air emissions, contaminants to water, oil spills and non-indigenious species and underwater noise emissions and also physical impacts such as ship wakes and anchoring and mooring. Compared to other drivers, shipping is determined as an important driver for the increase of non-indigenous species and physical impacts. NO_X, PM, and underwater noise are as well important pressures by shipping compared to other land and sea-based drivers. However, this does not mean these pressures are leading to the highest level of changes to the state of the environment or have the highest costs for human well being, e.g. CO_2 emissions have a variety of drivers and shipping is one of them and will lead to significant global effects. Most significant changes to the state of the environment in the Baltic Sea due to shipping can be summarized as invasive alien species, noise levels, oil spills and as well eutrophication, acidification and the loss of coastal vegetation. These changes have the potential to lead to significant impacts on ecosystem services and human well being and respectively costs of degradation for commercial fishing, recreational fishing, genetic resources, climate change mitigation, coastal protection, tourism and recreation, other socio-cultural services, and human health. Main impacts on human well being are expected to be losses to tourism and recreation as well as recreational fishing, mainly due to eutrophication and oil spills. In the Baltic States, both services have significant national socio-economic importance as well as being socio-economically relevant for selected local communities. Genetic resources can be especially influenced by invasive species. Other socio-cultural services might also be influenced significantly, e.g. inspriration and heritage. Human health is impacted by a broad variety of drivers but is probably influenced by shipping in selected local settings, e.g. especially where large harbours are close or in big cities.

Three case studies were implemented to focus on more specific pressures and their impact on ecosystem services and human well being. The first case study on air emissions shows that ozone and PM by shipping have a relevant impact on human health; it is evaluated with the ARP model with a mid range of EUR 2.8 billion for the year 2012 for the whole Baltic Sea; ranging between EUR 1.1 and 5.2 billion for 2012. The costs are due to an increase of respiratory and cardiovascular diseases. The second case study is focusing on potential effects on cod spawning areas due to nutrients, specifically NO_X emissions. Based on the assessment, the potential economic losses to the commercial cod fishing sector for 2012 are estimated between minimum EUR 1.2 million and maximum EUR 1.6 million; mid range EUR 1.4 million. The third case study analyses underwater noise emissions. Because of a lack of information and scientific results a full quantitative assessment of impacts on human well being was not possible. But the case study describes substantial interlinkages between noise and potential losses to commercial fishing and recreation fishing.

Abatement cost approach

Human activities, including shipping, produce both positive and negative environmental impacts to the environment (see section 2.2.2). Economists use the term "externality" to describe these impacts. Negative environmental externalities occur when the pollution level exceeds a threshold and causes damage to human health and the natural environment. Theoretically, an optimal level of pollution can be determined by solving a system of equations which includes damage cost and abatement cost functions. Damage costs refer to any type of economic loss caused by the pollution. Abatement costs refer to the expenditure on mitigating pollution levels or production lost from the policy of improving the environmental quality. A marginal cost derived from damage or abatement cost function is called the shadow price. Shadow prices are constructed prices for goods or production factors that are not traded in the markets. Shadow prices are used to evaluate the abatement quality, providing an indication of the value of abatement quality to the society.

The abatement costs of emissions from shipping activities are calculated using shadow prices and the amount of emissions of nine of the most typical air emissions and twelve of the most typical water contaminants and compounds. The shadow prices of water and air emissions were collected from previous studies, which were calculated at local, regional and global levels, and through different methods. The pollution levels are estimated in other work packages of the BONUS SHEBA project and used here. At first, average values of abatement costs are calculated. The uncertainties of the input data are considered by running simulation models, in which the values of shadow prices and pollution levels are randomly drawn from stochastic distributions of the input data.

In summary, the total abatement cost of air and water pollution caused by shipping in the Baltic Sea is EUR 4.70 billion in 2014, EUR 2.84 billion in 2030, and EUR 2.17 billion in 2040. The minimum costs for air and water pollution are estimated about 1 billion lower than the above mentioned values (EUR 3.88 billion in 2014, EUR 1.92 billion in 2030 and EUR 1.19 billion in 2040). RoPax ships, container ships, chemical tankers, general cargo ships and bulk cargo ships are the main contributors regarding pollution in terms of abatement cost.

The reduction of the costs is completely due to the improvement in air emissions as the average abatement costs linked to air emissions are predicted to amount to EUR 3.82 billion in 2014, EUR 1.83 billion in 2030, and EUR 1.07 billion in 2040. The abatement costs of air emissions are decreasing between 2014 and 2040 in the BAU by almost 72%. It is mainly due to improving technology, regulating environmental protection and updating the shipping management, factors, which were assumed in the *BAU scenario*. Taking the uncertainties of shadow prices and emission levels into consideration, there values can be reported with a certainty of about 60 %. Among 13 ship groups, RoPax ships, Container ships, Chemical Tanker and General Cargo Ships are main shares of the cost for air emissions. Among air emissions: NO_x, CO_2, PM and SO_2 are responsible for the majority of abatement costs due to emissions caused by shipping. Although the amount of NO_x emitted by shipping is much lower than the amount of CO_2, the abatement cost of NO_x is much higher. For 2014, the abatement cost of only NO_x made by shipping is EUR 2.5 billion, accounted for over 60 % of total abatement costs.

The by far lower share of abatement costs are linked to water pollution. With EUR 878 million, it is 19 % of the total in 2014. The share of abatement costs due to water emissions is increasing to 44 % in 2040 (EUR 1.1 billion). The cost could increase by 15.5 % in 2030 and 24.8 % in 2040, compared to 2014. Copper contaminants from shipping make up a large proportion of impacts on the ecosystem in terms of abatement cost. This metal's share is over 85 % of total abatement cost of water pollution from shipping. About 99 % of total polluted level of copper released to the sea is from antifouling activities. In difference to air emissions where RoPax and container ships have the highest share, the main ship types responsible for a major proportion of abatement costs of water contaminants are bulk cargo and general cargo.

Scenario assessment

To discuss future developments and how pressures by shipping could evolve, future scenarios developed in BONUS SHEBA (see section 1.2) are used for both assessment approaches. Three cumulative scenarios (linked to the Shared Socioeconomic Pathways (SSPs) developed by the Intergovernmental Panel on Climate Change (IPCC)) are used to discuss general, global socioeconomic trends. Seven single scenarios were developed within BONUS SHEBA and used to discuss specific pressures caused by shipping.

The cumulative scenarios are assessed with the ecosystem services approach. The cumulative scenarios are described with a sustainability, BAU and fragmentation scenario. The sustainability scenario assumes a decrease or stagnation of different pressures, resulting in decreasing costs of degradation to human well being compared to BAU. In the fragmentation scenario pressures are increasing, potentially decreasing human well being compared to BAU.

The individual scenarios are analysed along the ecosystem services approach (see section 3.2.3) and the abatement cost approach. The abatement costs are estimated for air emissions with an *NECA/NoNECA scenario* slow and a scenario with increased number of *LNG engines* (compared to BAU). For water pollutants, an enhanced *slow steaming scenario* and a *Zero emissions to water scenarios* was calculated. The ecosystem services approach assessed additionally: a *scenario including a transfer of land based traffic to the sea* and a *scenario including increased use of shore-side electricity in ports* (compared to BAU).

If we take all single scenarios into account (see section 3.3), the abatement costs are reduced most significantly by the *NECA/NoNECA scenario* which represents an implementation of a NECA area in 2021. It would potentially reduce the abatement costs by 25% in 2030 and almost 60 % in 2040 (compared to BAU). The *LNG scenario* is also reducing the abatement costs by about 13.7 % in 2030 and 14.2% in 2040 (compared to BAU).

The *Zero emissions to water scenario* resulting in lower emissions of nutrients and less transport of invasive species would reduce the abatement costs by 26 % in 2030 as well as 2040, compared to BAU. In the *slow steaming scenario* vessels will run 10% slower, therefore more vessels are required in the transport system in order to perform the same transport work. Compared to BAU, the *Slow Steaming Scenario* will reduce abatement cost of water pollution insignificantly at only 2.4 % in 2030 and 2.6 % in 2040.

Additionally, based on the ecosystem services approach we can say that most single scenarios are reducing air emissions. *NECA/NoNECA 2021 scenario* is focusing especially on NOX emissions and the *LNG scenario* shows different effects for different type of air emissions. The *Model shift from land to sea* would increase the air emissions with consequences of increased cost of all analysed components of human well being. For the water emissions, *Slow steaming* and *Model shift from land to sea scenario* are increasing the water emissions and therefore increasing the costs for human well being. The *Zero emissions to water scenario* is the only scenario decreasing emissions to water and decreasing the costs to all components of human well being. As described, the *Slow steaming* and *Modal shift from land to sea* would increase the number of vessels and therefore would also increase the pressure of underwater noise.

The results show that the environmental externalities and impacts on human well being by shipping could be reduced. At first based on the technologic improvements and adjusted regulations, which are already assumed in the BAU and would reduce the air emissions and their effects significantly. Different single scenarios show as well potential for a reduction of cost of degradation, especially the *LNG scenarios* shows a major effect on costs linked to air emissions. Costs from water emissions could be reduced by a *Zero emissions to water scenario*, e.g. including adjustments of the MARPOL regulations. The potential of policy measures will be further analysed in the BONUS SHEBA project.

Challenges and further research needs

A number of challenges and further research needs occurred during the assessment and should be mentioned and discussed. First, the design of the assessment framework, and the overall DPSIR framework, means that while linkages can be identified it was not possible to fully identify feedback loops within the system and account for their effects on human well being. In other words, the framework functions in a linear manner and the complexity of the complete system is not fully represented within the assessment. Similarly, while an attempt was made to provide an indication of importance regarding the specific elements (e.g. pressures) within the framework, it was not possible to do it in a way that allowed for the aggregation of pressures which resulted in cumulative changes to state because pressures are not measured in a harmonized way. However, it is not fully necessary to be able to aggregate pressures as this result is also captured in changes to state – so it could be assumed sufficient to have an understanding of the level of importance of shipping. Similarly, ecosystem services can be aggregated to final ecosystem services, identified through beneficiaries.

In regard to data, the assessment proved challenging with respect to a number of points. In many instances it was not possible to identify up-to-date or complete data sets linking to various elements of the assessment (i.e. pressures, state, and ecosystem services). Data was often not complete for the Baltic Sea area or was reported on a national level, meaning data was included for other marine areas, such as the North Sea.

Further research is also needed on comparison studies including all Baltic Sea countries on economic valuation of ecosystem services, e.g. stated or revealed preference studies. As benefit transfer from one country to the other is always including uncertainties and shortcomings, country comparison studies are valueable for the further improvement of ecosystem services assessment.

The DPSIR assessment framework is used to support the identification of effects to ecosystem services and human health from shipping activities. There are partial limitations to applying this approach due to research gaps. For example, little is known about the link between the noise levels and impacts on fish or mammals. The spatial area between the single case studies varies, due to data availability and to achieve results that reflect the Baltic region.

Main challenges regarding the case studies can be summarized. For the noise emissions case study that different sources for noise from shipping occur (cumulative pressures) which can not be summed up easily. Marine organisms are affected unequally to the different frequencies and that it is as well relevant when (day/night) and how long (duration) the noise occurs. All these characteristics make an easy judgement of impacts of underwater noise very difficult. A way forward could be the assessment of habitats. For different locations noise levels should be known and could be combined with the importance of habitat types for different fish or mammal species during their whole life history.

For the air case study, the methodology for the impact of human health and the monetization was already used in a number of European projects on climate mitigation and effects from investment in the transport system.

For the water case study we have focused on cod which is one of the key species in the Baltic Sea food chain. The cod population will simultaneously be affected by more factors than shipping and there will also be a lot of interactions between different layers in the food web but that has not been included or accounted for in the case study.

For the abatement cost assessment, the number and quality of sources for shadows prices show a broad variety between the different emissions. For some emissions especially water emissions, we have a very limited database for shadow prices which increases uncertainties for the estimation and also for the sensitivity analyses. Further research emphasis on the estimation of shadow prices should be considered.

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Appendix

Table A1. Abatement Cost of Air emissions of shipping in Baltic Sea (EUR million in 2014 value)

	BAU 2014								
Shipe types	**Total cost**	**CO2**	**CH4**	**N20**	**HC**	**CO**	**PM**	**SO2**	**NOX**
Container ship	628.90	76.13	0.02	1.06	4.81	0.49	51.27	72.70	422.42
General Cargo ship	415.59	55.86	0.01	0.72	3.08	0.42	35.65	56.55	263.29
Bulk Cargo Ship	313.79	35.21	0.01	0.48	2.31	0.25	24.98	36.66	213.88
RoRo ship	288.45	41.21	0.01	0.53	2.10	0.24	21.38	30.21	192.79
RoPax Ship	978.47	134.97	0.02	1.73	6.89	0.64	81.53	122.95	629.73
Vehicle Carrier	70.89	7.97	0.00	0.12	0.40	0.04	5.51	8.14	48.71
Refrigerated Cargo ship	61.13	6.76	0.00	0.09	0.42	0.04	4.51	6.60	42.70
Cruise ship	121.44	16.74	0.00	0.22	0.85	0.09	11.02	16.83	75.68
Oil Tanker	279.28	30.87	0.01	0.48	1.71	0.20	21.91	31.09	193.03
Product Tanker	117.45	14.05	0.00	0.18	0.79	0.08	9.39	13.38	79.55
Chemical Tanker	498.75	61.18	0.01	0.83	3.48	0.36	40.67	58.10	334.13
LNG Tanker	3.10	0.43	0.00	0.01	0.01	0.00	0.30	0.45	1.90
LPG Tanker	40.54	4.81	0.00	0.09	0.16	0.02	3.25	4.63	27.57

Sum	***3,817.78***	***486.18***	***0.09***	***6.52***	***27.03***	***2.87***	***311.38***	***458.31***	***2,525.39***
	BAU 2030								
	Total cost	**CO2**	**CH4**	**N20**	**HC**	**CO**	**PM**	**SO2**	**NOX**
Container ship	316.75	62.48	0.99	0.82	3.69	0.39	32.74	8.83	206.82
General Cargo ship	178.77	43.18	0.62	0.55	2.24	0.32	6.04	5.39	120.43
Bulk Cargo Ship	145.59	27.16	0.13	0.38	1.69	0.20	7.60	3.56	104.87
RoRo ship	130.58	32.69	1.04	0.39	1.47	0.17	6.05	2.57	86.21
RoPax Ship	392.28	103.56	5.39	1.12	4.26	0.41	15.78	8.64	253.12
Vehicle Carrier	38.34	6.72	0.03	0.10	0.33	0.03	3.89	0.95	26.28
Refrigerated Car-go	24.24	4.54	0.04	0.06	0.26	0.03	0.92	0.62	17.76
Cruise ship	59.47	14.04	0.16	0.18	0.69	0.07	5.25	1.67	37.42
Oil Tanker	165.92	30.24	0.33	0.46	1.57	0.20	10.62	3.90	118.61
Product Tanker	64.84	13.61	0.18	0.17	0.72	0.08	2.35	1.78	45.94
Chemical Tanker	280.12	59.46	0.72	0.77	3.17	0.34	12.18	7.72	195.75
LNG Tanker	2.01	0.42	0.00	0.01	0.01	0.00	0.21	0.05	1.30
LPG Tanker	25.62	4.72	0.03	0.09	0.15	0.02	1.36	0.63	18.62
Sum	***1,824.53***	***402.81***	***9.67***	***5.10***	***20.27***	***2.26***	***104.99***	***46.31***	***1,233.11***
	BAU 2040								
	Total cost	**CO2**	**CH4**	**N20**	**HC**	**CO**	**PM**	**SO2**	**NOX**

Container ship	185.68	55.35	1.26	0.70	3.21	0.33	35.01	7.61	82.22
General Cargo ship	96.99	37.42	0.88	0.46	1.87	0.27	5.21	4.50	46.38
Bulk Cargo Ship	80.90	23.56	0.17	0.32	1.46	0.17	7.85	3.06	44.31
RoRo ship	74.34	28.51	1.36	0.31	1.20	0.14	5.95	2.09	34.77
RoPax Ship	219.70	89.00	7.04	0.84	3.21	0.31	14.21	6.51	98.57
Vehicle Carrier	23.59	6.00	0.04	0.09	0.30	0.03	4.30	0.84	11.99
Refrigerated Cargo ship	11.84	3.60	0.05	0.05	0.21	0.02	0.81	0.48	6.63
Cruise ship	35.53	12.67	0.21	0.16	0.61	0.06	5.68	1.48	14.66
Oil Tanker	108.88	30.35	0.48	0.45	1.55	0.19	12.81	3.84	59.20
Product Tanker	39.67	13.58	0.27	0.17	0.70	0.08	2.43	1.73	20.71
Chemical Tanker	175.33	59.44	1.06	0.75	3.10	0.33	13.31	7.55	89.78
LNG Tanker	1.56	0.43	0.00	0.01	0.01	0.00	0.26	0.05	0.80
LPG Tanker	18.52	4.74	0.04	0.09	0.15	0.02	1.51	0.63	11.34
Sum	***1,072.54***	***364.65***	***12.89***	***4.39***	***17.57***	***1.95***	***109.34***	***40.38***	***521.37***

	NECA scenario (Abatement Cost of NOx)					
	2014		**2030**		**2040**	
	NECA 2014	**noNECA 2014**	**NECA 2030**	**noNECA 2030**	**NECA 2040**	**noNECA 2040**
Container ship	422.46	422.46	207.02	281.39	82.04	217.75

General Cargo ship	262.99	262.99	120.38	161.01	46.39	118.08
Bulk Cargo Ship	213.92	213.92	105.04	140.31	44.32	108.87
RoRo ship	192.45	192.45	85.87	112.71	34.81	80.51
RoPax Ship	629.48	629.48	253.02	330.46	98.91	221.58
Vehicle Carrier	48.69	48.69	26.30	34.43	11.96	27.22
Refrigerated Cargo ship	42.71	42.71	17.79	23.85	6.63	16.56
Cruise ship	75.68	75.68	37.42	50.07	14.64	38.18
Oil Tanker	193.21	193.21	118.84	157.94	59.19	140.31
Product Tanker	79.74	79.74	45.93	61.49	20.70	52.67
Chemical Tanker	334.29	334.29	195.51	262.22	89.71	226.18
LNG Tanker	1.90	1.90	1.30	1.63	0.80	1.50
LPG Tanker	27.60	27.60	18.63	23.39	11.35	21.24
Total cost	***2,522.52***	***2,522.52***	***1,234.42***	***1,640.79***	***521.37***	***1,272.76***

	Abatement cost of Emission LNG scenario 2030								
	Total cost	CO2	CH4	N2O	HC	CO	PM	SO2	NOX
Container ship	287.11	60.20	2.59	0.71	3.19	0.33	31.56	7.59	180.95
General Cargo ship	163.69	41.70	1.63	0.48	1.96	0.28	5.58	4.72	107.34
Bulk Cargo Ship	141.57	26.90	0.33	0.36	1.63	0.19	7.53	3.42	101.21

RoRo ship	105.25	30.34	2.75	0.27	1.03	0.12	5.39	1.80	63.56
RoPax Ship	260.21	91.48	14.27	0.51	1.95	0.19	12.06	4.03	135.71
Vehicle Carrier	37.24	6.63	0.09	0.09	0.32	0.03	3.87	0.91	25.30
Refrigerated Cargo ship	22.93	4.47	0.10	0.06	0.25	0.03	0.89	0.58	16.56
Cruise ship	55.85	13.69	0.41	0.16	0.62	0.06	5.12	1.51	34.27
Oil Tanker	155.16	29.49	0.87	0.42	1.42	0.18	10.37	3.54	108.87
Product Tanker	59.47	13.18	0.48	0.15	0.64	0.07	2.19	1.57	41.17
Chemical Tanker	259.19	57.85	1.90	0.69	2.84	0.31	11.60	6.90	177.11
LNG Tanker	1.96	0.42	0.01	0.01	0.01	0.00	0.21	0.05	1.25
LPG Tanker	24.68	4.64	0.08	0.08	0.14	0.02	1.33	0.60	17.79
Sum	***1,574.50***	***380.03***	***25.52***	***3.99***	***16.01***	***1.80***	***97.83***	***37.26***	***1,012.07***

	Abatement cost of Emission LNG scenario 2040								
	Total cost	CO2	CH4	N2O	HC	CO	PM	SO2	NOX
Container ship	167.94	52.46	3.32	0.55	2.56	0.26	33.65	6.05	69.08
General Cargo ship	86.81	35.31	2.32	0.36	1.47	0.21	4.56	3.55	39.03
Bulk Cargo Ship	78.15	23.17	0.45	0.30	1.37	0.16	7.73	2.87	42.09
RoRo ship	58.83	25.43	3.59	0.16	0.62	0.07	5.10	1.09	22.77
RoPax Ship	144.56	74.32	17.75	0.10	0.42	0.04	9.72	0.95	41.25

Vehicle Carrier	22.87	5.89	0.12	0.08	0.28	0.03	4.26	0.79	11.42
Refrigerated Cargo ship	11.05	3.50	0.13	0.04	0.18	0.02	0.77	0.42	5.98
Cruise ship	33.36	12.21	0.55	0.13	0.52	0.05	5.52	1.26	13.11
Oil Tanker	100.91	29.26	1.27	0.38	1.34	0.16	12.44	3.31	52.75
Product Tanker	36.04	12.98	0.71	0.14	0.58	0.06	2.19	1.43	17.94
Chemical Tanker	161.26	57.17	2.80	0.63	2.61	0.28	12.46	6.33	78.97
LNG Tanker	1.51	0.42	0.01	0.01	0.01	0.00	0.26	0.05	0.76
LPG Tanker	17.77	4.64	0.12	0.08	0.14	0.02	1.47	0.58	10.73
Sum	***920.31***	***336.31***	***33.13***	***2.97***	***12.08***	***1.36***	***100.13***	***28.73***	***405.60***

Table A2. Abatement Cost of Water Pollution of shipping in Baltic Sea (EUR million in 2014 value)

BAU 2014													
Shipe types	**Total**	**As**	**Cd**	**Co**	**Cu**	**CHBr2 Cl**	**Pb**	**Hg**	**C10H 8**	**Ni**	**N**	**P**	**C16H 10**	**Zn**
Container ship	72.1	0.001	0.000	0.000	69.571	0.015	0.000	0.000	0.004	0.038	0.172	1.005	0.000	1.288
General Cargo ship	152.6	0.003	0.001	0.002	146.029	0.031	0.001	0.001	0.010	0.032	0.403	3.098	0.000	2.943
Bulk Cargo Ship	169.5	0.001	0.000	0.000	165.336	0.018	0.000	0.000	0.003	0.007	0.143	1.156	0.000	2.879
RoRo ship	30.8	0.001	0.000	0.160	28.840	0.010	0.003	0.001	0.002	0.140	0.113	0.806	0.002	0.734
RoPax Ship	110.3	0.027	0.007	0.182	41.966	0.227	0.024	0.018	0.038	0.413	6.880	58.537	0.003	1.941
Vehicle Carrier	9.2	0.000	0.000	0.000	8.942	0.002	0.000	0.000	0.000	0.001	0.013	0.106	0.000	0.156
Refrigerated Cargo	11.2	0.000	0.000	0.000	10.838	0.001	0.000	0.000	0.001	0.001	0.016	0.133	0.000	0.190

ship														
Cruise ship	32.2	0.004	0.001	0.004	15.799	0.035	0.003	0.003	0.005	0.040	1.398	14.548	0.000	0.400
Oil Tanker	122.5	0.000	0.000	0.000	119.749	0.011	0.000	0.000	0.002	0.002	0.074	0.584	0.000	2.099
Product Tanker	38.0	0.000	0.000	0.000	36.996	0.004	0.000	0.000	0.001	0.001	0.035	0.277	0.000	0.668
Chemical Tanker	119.9	0.001	0.000	0.000	116.330	0.013	0.000	0.000	0.004	0.022	0.180	1.219	0.000	2.126
LNG Tanker	2.3	0.000	0.000	0.000	2.216	0.000	0.000	0.000	0.000	0.000	0.001	0.007	0.000	0.038
LPG Tanker	7.4	0.000	0.000	0.000	7.149	0.001	0.000	0.000	0.000	0.001	0.010	0.078	0.000	0.129
SUM	**877.9**	**0.03873**	**0.01066**	**0.34914**	**769.76258**	**0.36537**	**0.03316**	**0.02481**	**0.06956**	**0.69750**	**9.43820**	**81.55411**	**0.00513**	**15.58932**
BAU 2030														
Shipe types	**Total**	**As**	**Cd**	**Co**	**Cu**	**CHBr2Cl**	**Pb**	**Hg**	**C10H8**	**Ni**	**N**	**P**	**C16H10**	**Zn**
Container ship	93.3	0.002	0.002	1.017	86.499	0.017	0.019	0.006	0.003	1.174	0.706	1.430	0.015	2.432
General Cargo ship	153.1	0.003	0.001	0.013	146.606	0.031	0.001	0.001	0.008	0.032	0.389	3.090	0.000	2.962
Bulk Cargo Ship	180.7	0.001	0.001	0.254	175.286	0.019	0.005	0.002	0.003	0.298	0.287	1.254	0.004	3.262
RoRo ship	35.2	0.001	0.001	0.248	32.486	0.012	0.005	0.002	0.002	0.290	0.250	0.976	0.004	0.882
RoPax Ship	130.2	0.032	0.009	0.350	47.905	0.272	0.031	0.023	0.036	0.679	8.361	70.117	0.005	2.359
Vehicle Carrier	12.0	0.000	0.000	0.162	11.000	0.002	0.003	0.001	0.000	0.186	0.105	0.168	0.002	0.326
Refrigerated Cargo ship	11.4	0.000	0.000	0.014	10.971	0.001	0.000	0.000	0.000	0.017	0.024	0.136	0.000	0.204
Cruise ship	38.3	0.005	0.002	0.238	18.172	0.041	0.008	0.004	0.005	0.315	1.768	17.110	0.004	0.653
Oil Tanker	153.4	0.001	0.001	0.350	148.621	0.014	0.007	0.002	0.002	0.405	0.282	0.794	0.005	2.893
Product Tanker	46.5	0.000	0.000	0.015	45.291	0.005	0.000	0.000	0.001	0.019	0.050	0.337	0.000	0.830
Chemical Tanker	148.3	0.001	0.001	0.178	143.283	0.018	0.004	0.001	0.004	0.210	0.285	1.516	0.003	2.764
LNG Tanker	2.9	0.000	0.000	0.010	2.772	0.000	0.000	0.000	0.000	0.011	0.006	0.011	0.000	0.055
LPG Tanker	9.3	0.000	0.000	0.025	8.897	0.001	0.000	0.000	0.000	0.029	0.026	0.100	0.000	0.180
SUM	**1,014.4**	**0.0469**	**0.0162**	**2.8749**	**877.7884**	**0.4319**	**0.0850**	**0.0421**	**0.0646**	**3.6651**	**12.5402**	**97.0397**	**0.0432**	**19.8024**
BAU 2040														
Shipe types	**Total**	**As**	**Cd**	**Co**	**Cu**	**CHBr2Cl**	**Pb**	**Hg**	**C10H8**	**Ni**	**N**	**P**	**C16H10**	**Zn**
Container ship	101.9	0.003	0.002	1.208	94.035	0.019	0.023	0.007	0.003	1.395	0.826	1.597	0.018	2.729
General Cargo	153.2	0.003	0.001	0.016	146.620	0.031	0.001	0.001	0.007	0.034	0.390	3.085	0.000	2.964

ship														
Bulk Cargo Ship	186.6	0.001	0.001	0.295	180.920	0.019	0.006	0.002	0.002	0.345	0.313	1.286	0.004	3.393
RoRo ship	37.5	0.001	0.001	0.295	34.536	0.013	0.006	0.002	0.002	0.344	0.287	1.081	0.004	0.963
RoPax Ship	142.0	0.034	0.009	0.415	51.131	0.300	0.035	0.025	0.034	0.781	9.249	77.425	0.006	2.578
Vehicle Carrier	12.9	0.000	0.000	0.192	11.763	0.002	0.004	0.001	0.000	0.221	0.123	0.188	0.003	0.364
Refrigerated Cargo ship	11.4	0.000	0.000	0.015	10.978	0.001	0.000	0.000	0.000	0.018	0.025	0.136	0.000	0.205
Cruise ship	41.2	0.005	0.002	0.288	18.888	0.045	0.009	0.005	0.005	0.376	1.966	18.902	0.004	0.720
Oil Tanker	174.2	0.001	0.001	0.471	168.541	0.017	0.009	0.003	0.002	0.544	0.360	0.912	0.007	3.341
Product Tanker	52.7	0.000	0.000	0.020	51.228	0.006	0.000	0.000	0.001	0.025	0.059	0.380	0.000	0.941
Chemical Tanker	168.0	0.001	0.001	0.240	162.257	0.021	0.005	0.002	0.004	0.282	0.342	1.715	0.004	3.161
LNG Tanker	3.3	0.000	0.000	0.013	3.148	0.000	0.000	0.000	0.000	0.015	0.008	0.013	0.000	0.065
LPG Tanker	10.5	0.000	0.000	0.033	10.095	0.001	0.001	0.000	0.000	0.039	0.032	0.114	0.001	0.209
SUM	**1,095.3**	**0.0510**	**0.0180**	**3.5016**	**944.1401**	**0.4759**	**0.0998**	**0.0481**	**0.0616**	**4.4196**	**13.9800**	**106.8353**	**0.0526**	**21.6320**

No water Emission 2030

Shipe types	**Total**	**As**	**Cd**	**Co**	**Cu**	**CHBr2Cl**	**Pb**	**Hg**	**C10H8**	**Ni**	**N**	**P**	**C16H10**	**Zn**
Container ship	71.7	0.001	0.000	-	68.732	0.008	0.001	0.000	-	0.683	1.014	-	-	1.267
General Cargo ship	128.3	0.000	0.000	-	125.779	0.006	0.000	0.000	-	0.008	0.013	-	-	2.496
Bulk Cargo Ship	166.4	0.000	0.000	-	163.143	0.009	0.000	0.000	-	0.171	0.253	-	-	2.827
RoRo ship	15.9	0.000	0.000	-	15.137	0.004	0.000	0.000	-	0.166	0.247	-	-	0.315
RoPax Ship	13.2	0.000	0.000	-	12.293	0.008	0.000	0.000	-	0.225	0.334	-	-	0.329
Vehicle Carrier	8.4	0.000	0.000	-	7.972	0.001	0.000	0.000	-	0.109	0.161	-	-	0.139
Refrigerated Cargo ship	11.1	0.000	0.000	-	10.868	0.000	0.000	0.000	-	0.010	0.014	-	-	0.188
Cruise ship	15.1	0.000	0.000	-	14.482	0.001	0.000	0.000	-	0.159	0.236	-	-	0.264
Oil Tanker	137.6	0.000	0.000	-	134.634	0.011	0.000	0.000	-	0.235	0.349	-	-	2.355
Product Tanker	41.9	0.000	0.000	-	41.108	0.003	0.000	0.000	-	0.010	0.015	-	-	0.739
Chemical Tanker	133.4	0.000	0.000	-	130.687	0.012	0.000	0.000	-	0.120	0.178	-	-	2.374
LNG Tanker	2.8	0.000	0.000	-	2.709	0.000	0.000	0.000	-	0.007	0.010	-	-	0.046
LPG Tanker	8.9	0.000	0.000	-	8.732	0.001	0.000	0.000	-	0.017	0.025	-	-	0.156
SUM	**754.6**	**0.0020**	**0.0001**	**-**	**736.2756**	**0.0657**	**0.0014**	**0.0003**	**-**	**1.9179**	**2.8487**	**-**	**-**	**13.4959**

		68	10		35	14	79	36		16	82			49
No water Emission 2040														
Shipe types	**Total**	**As**	**Cd**	**Co**	**Cu**	**CHBr2 Cl**	**Pb**	**Hg**	**C10H 8**	**Ni**	**N**	**P**	**C16H 10**	**Zn**
Container ship	77.6	0.001	0.000	-	74.154	0.009	0.001	0.000	-	0.812	1.206	-	-	1.368
General Cargo ship	128.3	0.000	0.000	-	125.779	0.006	0.000	0.000	-	0.010	0.015	-	-	2.496
Bulk Cargo Ship	171.6	0.000	0.000	-	168.193	0.010	0.000	0.000	-	0.198	0.294	-	-	2.915
RoRo ship	16.8	0.000	0.000	-	15.998	0.005	0.000	0.000	-	0.198	0.294	-	-	0.333
RoPax Ship	14.0	0.000	0.000	-	12.997	0.009	0.000	0.000	-	0.267	0.397	-	-	0.348
Vehicle Carrier	8.9	0.000	0.000	-	8.426	0.001	0.000	0.000	-	0.129	0.192	-	-	0.148
Refrigerated Cargo ship	11.1	0.000	0.000	-	10.868	0.000	0.000	0.000	-	0.010	0.015	-	-	0.188
Cruise ship	15.5	0.000	0.000	-	14.775	0.001	0.000	0.000	-	0.192	0.285	-	-	0.270
Oil Tanker	155.7	0.000	0.000	-	152.244	0.014	0.000	0.000	-	0.316	0.470	-	-	2.664
Product Tanker	47.4	0.000	0.000	-	46.479	0.004	0.000	0.000	-	0.014	0.020	-	-	0.835
Chemical Tanker	150.9	0.000	0.000	-	147.770	0.014	0.000	0.000	-	0.161	0.239	-	-	2.685
LNG Tanker	3.1	0.000	0.000	-	3.064	0.000	0.000	0.000	-	0.009	0.013	-	-	0.052
LPG Tanker	10.1	0.000	0.000	-	9.874	0.001	0.000	0.000	-	0.022	0.033	-	-	0.177
SUM	**811.0**	**0.003**	**0.000**	**-**	**790.622**	**0.075**	**0.002**	**0.000**	**-**	**2.338**	**3.473**	**-**	**-**	**14.478**
Slow Steam 2030														
Shipe types	**Total**	**As**	**Cd**	**Co**	**Cu**	**CHBr2 Cl**	**Pb**	**Hg**	**C10H 8**	**Ni**	**N**	**P**	**C16H 10**	**Zn**
Container ship	94.9	0.002	0.002	0.824	88.650	0.018	0.016	0.005	0.003	0.953	0.608	1.450	0.012	2.314
General Cargo ship	157.4	0.003	0.001	0.011	150.620	0.032	0.001	0.001	0.007	0.030	0.405	3.227	0.000	3.041
Bulk Cargo Ship	184.9	0.001	0.001	0.206	179.527	0.019	0.004	0.002	0.002	0.243	0.267	1.290	0.003	3.296
RoRo ship	35.7	0.001	0.001	0.201	33.109	0.012	0.004	0.001	0.002	0.236	0.231	1.018	0.003	0.858
RoPax Ship	92.2	0.019	0.007	0.287	47.570	0.107	0.030	0.018	0.019	0.551	2.138	39.211	0.004	2.242
Vehicle Carrier	12.0	0.000	0.000	0.131	11.131	0.002	0.002	0.001	0.000	0.151	0.089	0.168	0.002	0.303
Refrigerated Cargo ship	11.6	0.000	0.000	0.012	11.226	0.001	0.000	0.000	0.000	0.014	0.023	0.141	0.000	0.206
Cruise ship	33.6	0.003	0.001	0.194	18.240	0.019	0.007	0.004	0.003	0.257	0.937	13.316	0.003	0.610
Oil Tanker	156.3	0.001	0.001	0.283	151.675	0.015	0.005	0.002	0.002	0.328	0.249	0.801	0.004	2.891

Product Tanker	47.4	0.000	0.000	0.012	46.143	0.005	0.000	0.000	0.001	0.015	0.050	0.346	0.000	0.843
Chemical Tanker	152.2	0.001	0.001	0.145	147.220	0.018	0.003	0.001	0.003	0.172	0.274	1.572	0.002	2.808
LNG Tanker	2.9	0.000	0.000	0.008	2.812	0.000	0.000	0.000	0.000	0.009	0.005	0.011	0.000	0.055
LPG Tanker	9.5	0.000	0.000	0.020	9.110	0.001	0.000	0.000	0.000	0.023	0.024	0.103	0.000	0.180
SUM	**990.4**	**0.032**	**0.014**	**2.333**	**897.031**	**0.251**	**0.075**	**0.035**	**0.042**	**2.982**	**5.300**	**62.653**	**0.035**	**19.646**

Slow Steam 2040														
Shipe types	**Total**	**As**	**Cd**	**Co**	**Cu**	**CHBr2 Cl**	**Pb**	**Hg**	**C10H 8**	**Ni**	**N**	**P**	**C16H 10**	**Zn**
Container ship	103.2	0.002	0.002	0.979	96.161	0.021	0.019	0.006	0.003	1.132	0.709	1.616	0.015	2.581
General Cargo ship	157.3	0.003	0.001	0.013	150.510	0.032	0.001	0.001	0.006	0.032	0.406	3.223	0.000	3.043
Bulk Cargo Ship	190.8	0.001	0.001	0.239	185.203	0.020	0.005	0.002	0.002	0.281	0.288	1.321	0.004	3.422
RoRo ship	38.0	0.001	0.001	0.239	35.112	0.014	0.005	0.002	0.002	0.280	0.264	1.127	0.004	0.932
RoPax Ship	100.0	0.021	0.008	0.340	50.686	0.118	0.033	0.020	0.017	0.634	2.372	43.291	0.005	2.443
Vehicle Carrier	12.8	0.000	0.000	0.156	11.868	0.002	0.003	0.001	0.000	0.179	0.104	0.188	0.002	0.336
Refrigerated Cargo ship	11.6	0.000	0.000	0.012	11.225	0.001	0.000	0.000	0.000	0.015	0.024	0.140	0.000	0.207
Cruise ship	35.9	0.004	0.002	0.234	18.876	0.021	0.008	0.004	0.003	0.306	1.045	14.710	0.003	0.667
Oil Tanker	177.3	0.001	0.001	0.381	171.884	0.018	0.007	0.002	0.002	0.441	0.315	0.918	0.006	3.326
Product Tanker	53.6	0.000	0.000	0.016	52.181	0.006	0.000	0.000	0.001	0.020	0.058	0.389	0.000	0.955
Chemical Tanker	172.4	0.001	0.001	0.195	166.631	0.022	0.004	0.001	0.003	0.230	0.326	1.777	0.003	3.204
LNG Tanker	3.3	0.000	0.000	0.011	3.190	0.000	0.000	0.000	0.000	0.012	0.007	0.013	0.000	0.063
LPG Tanker	10.7	0.000	0.000	0.027	10.327	0.001	0.001	0.000	0.000	0.032	0.029	0.117	0.000	0.208
SUM	**1,067 .0**	**0.035**	**0.015**	**2.841**	**963.855**	**0.276**	**0.087**	**0.040**	**0.039**	**3.594**	**5.947**	**68.830**	**0.043**	**21.387**