BONUS SHEBA PROJECT (1 April 2015 – 31 July 2018)

The final publishable summary report

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Project outline of goals and results envisaged at the beginning of the project cycle

Since centuries shipping has been a major means of trade in the region. The number of ships employed has increased tremendously and is projected to increase further over the next decades. In recent years a considerable fleet of cruise ships has developed and countless leisure boats – sailing and/or motorized – are in use for human recreation. There are several paths by which ship operations impact the environment. Among them are emissions of exhaust gases and particles to the air, emissions of contaminants through releases of sewage, ballast and scrubber water as well as leakage of antifouling paint into the sea and emissions of under- and above water level noise. Also impact of shipping on climate is of relevance. The main goal of the BONUS SHEBA project (Sustainable Shipping and Environment of the Baltic Sea Region) was a holistic assessment of ecological, economic and societal impacts of operational shipping on the environment of the Baltic Sea region. The project methodology was to develop a Driver-Pressure-State-Impact-Response (DPSIR) assessment framework including the currently most advanced tools and models for determination of environmental pressures from shipping which would, in combination with evaluation of different future scenarios, also enable possibilities to test options for regulations and other policy measures that aim at the reduction of pressures, improvements of the state and minimized impacts on human health and ecosystems.

Work carried out in the project

Work in BONUS SHEBA was organised in closely cooperating scientific work packages of which three focused on specific pollutants (WP2: air pollution, WP3: water pollution and WP4: underwater noise) while other two had a more overarching and integrating role (WP1: scenarios and shipping activity data, WP5: assessment). A separate work package (WP6) was devoted to outreach and dissemination of BONUS SHEBA results to scientific community, stakeholders and wide public.

The work package on Policies, activity data and scenarios (WP1) contained several parts. As a basis for the further work in all WPs models of the ship traffic in the Baltic Sea were produced. These were based on ship activity data from the Automatic Identification System (AIS) and data on all individual ships present in the area regarding ship type, size, fuel type, engine type etc. This model was then used in the other WPs, together with emission factors, to produce maps of emissions to air and water and of underwater noise. An important part of WP1 was to produce a number of scenarios of shipping activities in the future, aiming at the years 2030 and 2040. In order to produce these scenarios a complete mapping of the drivers governing future shipping was undertaken. This includes drivers regarding shipping volumes and developments of ship design as well as the legislations that will come into action during the period, with emphasis on environmental policy measures. With this information in place a business as usual scenario was constructed. Further, in order to investigate different other possible developments a number of alternative scenarios have been constructed. These include a set of scenarios to answer specific questions, i.e. what was the impact of the NO_x regulations?; what will be the consequence of a strong modal transfer from land to sea?; what would a large introduction of Liquified Natural Gas (LNG) as a marine fuel mean?, among others. Secondly, shipping activities in two additional cumulative scenarios used in climate research (Sustainability and Fragmentation) were analysed. These were also used to identify the gaps between what is expected from shipping in the future and what is needed for shipping to become sustainable. In addition, WP1 developed a model for leisure boat traffic in the Baltic Sea, the first such comprehensive model. This is used to calculate emissions to air and water from the leisure boat traffic.

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In the work package on air pollution updated high resolution shipping emission data for the Baltic Sea in the year 2012 were calculated with the Ship Traffic Assessment Model (STEAM, Jalkanen et al., 2009; 2012; Johansson et al., 2013). These data were produced on a 2 x 2 km² grid for emissions of SO_2, NO_x, CO, CO_2 and particulate matter (including SO_4, elemental carbon, organic carbon and ash) for the entire Baltic Sea. In the port areas of Gothenburg, Rostock, Gdansk and Riga, the data were provided on a resolution of 250 x 250 m².

Subsequently, regional and city scale atmospheric chemistry models were applied for calculating the impact of emissions from shipping on the Baltic Sea on air quality and on the deposition of eutrophying and acidifying substances. Three regional-scale chemistry transport models (CTMs) were used in an ensemble simulation of the impact of year 2012 shipping emissions in the Baltic Sea region. Four port cities were studied employing two urban-scale models. In 2012, shipping was responsible for more than 20% of the NO_2 in coastal areas in summer, on the Baltic Sea more than 80% of the NO_2 stems from shipping. These emissions lead to increased ozone concentrations by approximately 10% and about 20-30% increased particulate nitrate over land in summer. The impact of shipping on air quality is much smaller in winter. In harbour cities, mainly NO_2 concentrations are increased due to shipping emissions. Whether this has large effects on the exposure of the population depends strongly on the location of the port area with respect to the main wind direction.

Three different future scenarios on Baltic Sea shipping in 2040 were investigated in detail. It could be shown that reduced fuel consumption achieved by efficiency increases together with strict regulations on sulphur and NO_x emissions will lead to significant reductions of the impact of shipping on air pollution in the Baltic Sea area. Until 2040, the contribution of shipping to air pollution in harbour cities will be significantly reduced too. The provision of on shore power supply will contribute to this.

The modelled air pollutant concentrations served as input for the calculation of health effects in the Baltic Sea region caused by shipping emissions and the associated external costs using the Alpha-Riskpoll tool (Holland et al., 2013). The results showed that in year 2012 the shipping emission caused some 16 000 life years lost or 1 600 premature deaths due to the exposure to fine PM, representing approximately 8% of the overall negative health impacts caused by air pollution with fine particulate matter in the region. For year 2040 the impacts decreased by more than 70% in the Business As Usual (BAU) scenario, ~50% of this decrease being associated with the introduction of the stricter Sulphur Emission Control Area (SECA) regulations in 2015 together with the predicted increase in energy efficiency of shipping. Further, over 20% of this decrease is associated with the implementation of the Nitrogen Emission Control Area (NECA). A health impact study performed for the city of Gothenburg showed that while contribution of local shipping to the negative health effects from fine PM in the city was ~2%, contribution from regional shipping outside the city was more than 10% in 2012. The modelled deposition data from the regional simulations were further used to assess the extent of environmental damage on the land ecosystems surrounding the Baltic Sea due to ship emissions of S and N by calculating the exceedance of critical loads for eutrophication and acidification. Also these results show a significant improvement from 2012 to 2040. For the acidification a decrease in exceedances from about 4% of the area in 2012 to about 1% in 2040 illustrates the effectiveness and the benefits of the implementation of the stricter SECA regulations in 2015. For eutrophication there are also improvements, from critical loads exceeded at 27% of the considered area in 2012 to between 9 – 10% in 2040, depending on scenario.

In work package 3, the summarized pressures on the marine environment were calculated as 1) fate and effect of nutrient inputs, 2) surface water pH change, 3) distribution and viability of invasive species and the ratio between Predicted Environmental Concentration and Predicted No Effect Concentration (PEC/PNEC ratio) or the Sum of Toxic Units (STU) from shipping related top ranked contaminant input. Shipping related nano- and micro-particles are of emerging interest and data are

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reported in the project, however, as of today, the data are too scarce to be used in a full modelling. The change in state in the marine environment was modelled linking the output from the STEAM model and deposition from the atmospheric modelling to an oceanographic circulation model (GETM) and a coupled biogeochemical model (ERGOM), producing maps visualizing the impact of shipping on the marine environment. Further, in situ observations confirmed that shipping related emissions can be observed in shipping lanes which calls for further investigations. The impact of shipping on the marine environment along five potential future scenarios (BAU, No Nitrogen Emission Control Area (NoNECA), Zero emission to water and two scrubbers scenarios (All open loop and All closed loop) were analysed for the years 2030 and 2040, and in relation to the two EU Directives: the Marine Strategy Framework Directive (MSFD) and the Water Framework Directive (WFD). The results showed that shipping input of nitrogen to the Baltic Sea was ca 20 ktonne in 2012, corresponding to 2.5% of the total input and 14% of total atmospheric deposition. For the BAU 2040 scenario the shipping input was forecasted to decrease by more than 80%, to 3.3 ktonne, but due to decreased background emission, the shipping share decreases less, to approximately 4.7%. The shipping contribution to input of oxidised nitrogen is to a very large extent dominated by atmospheric deposition; only approximately 1.4% (year 2012) of the NO_3-N originating from ships enters the Baltic Sea via discharge of black, grey, and bilge water. In the NoNECA scenario the amount of nitrogen originating from atmospheric emissions from ships is 10 ktonne, i.e. 14% of the total nitrogen deposition, while the direct discharges remain the same. Phosphorus input from shipping was approximately 0.5% of the total input to the Baltic Sea, and the origin was dominated by black water (60%), deposited ash originating from the emissions to air (25%) and grey water (13%) in 2012. Despite the regulations assumed for the BAU 2040 scenario concerning wastewater emissions for passenger ships, black water emissions for the year 2040 will be still largest source for ammonia and phosphates due to the high number of cargo ships, for which the wastewater emission regulation does not apply. The effect on phytoplankton and cyanobacterial blooms from the nutrients emitted from shipping can at times be in the range of 5 % - 10 % and a negative effect on MSFD Descriptor 5, *Eutrophication is minimized* may occur, especially on local scale. Regarding contaminants, 5 representative pollutants were modelled; copper, zinc, dibromochloromethane, naphthalene and pyrene. Clearly, the compounds with the highest emission are copper and zinc. It can be noted that the calculated copper emissions form shipping in the Baltic Sea for the reference year 2012 (302 tons) are of similar magnitude as the input of copper through river inflow from Sweden in 2006 (239 tons) and are approximately one third of the total copper input through the river inflow to the Baltic Sea (886 tons), as assessed by HELCOM (2011). According to the BONUS SHEBA BAU scenario, the copper and zinc emissions from shipping will increase due to an expected increase in traffic. Beyond the 5 model pollutants a cumulative risk assessment was made for 62 shipping related contaminants for two shipping lanes (one northeast of Bornholm in the Baltic Proper and one east of Anholt in the Kattegat) and three harbours (Muuga, Primorsk and Gdynia). The risk ratio for each contaminant was calculated as the PEC/PNEC ratio. A risk ratio above 1 indicates that there is an environmental risk from the contaminants emitted from shipping and if background concentrations were included in the analysis, the risks for all studied harbours, surrounding harbour areas and shipping lanes had a cumulative risk ratio above 1 (1.1 – 8.3). It should be stressed though that the cumulative assessment of contaminants from shipping used in the oceanographic model only included a subset of contaminants, hence the effect on MSFD D8 *Concentrations of contaminants give no effects*, is likely underestimated.

The work package on underwater noise (WP 4) started with the development of new tools for noise modelling. A review of existing noise models was done and a recent German model (Wittekind, 2014) for shipping noise emissions was selected for implementation. The model was adapted to fit the existing STEAM emission model. A new approach was developed for noise emission reporting, which visualizes noise as a map of noise energy. This facilitates annual updates of noise source maps for HELCOM reporting. Noise source maps could not be directly used in noise propagation modelling which was required to understand the noise dispersion in the Baltic Sea. Two pilot locations were

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chosen for noise propagation studies where measured and modelled data were available to assess the performance of the modelling work. Impact assessment of underwater noise could not be completed as planned because of limitations of existing exposure-response functions for noise exposure of fish and mammals and lack of knowledge of other than shipping noise sources. As a basic analysis of the potential impacts a map of overlaps in species habitats and shipping noise emissions was made. In addition to the modelling work, experimental work was carried out at the Tvärminne zoological station. Collections of local fish were exposed to various noise signatures and behavioural changes were observed with sonar equipment. Tones at specific frequencies and pre-recorded shipping noise were played back to fish using underwater loudspeakers. These triggered clear reactions in fish schools, but understanding the harmfulness of noise to fish needs more research work.

The work package on assessments and policies (WP 5) researched existing DPSIR (Driver-Pressure-State-Impact-Response) frameworks. Based on the review a DPSIR framework was developed for the assessment of environmental pressures of shipping in the Baltic Sea to assess the linkages from the pressures of shipping to their effects on ecosystem services and human wellbeing. The costs of degradation from environmental and health related impacts of shipping in the Baltic were analysed. Based on the developed DPSIR framework, effects on a variety of ecosystem services and human health was evaluated qualitatively. Effects on ecosystem services were quantitatively assessed for two case studies – one for commercial fishing of cod and the second calculated human health effects caused by air pollution from shipping. Further, 20 policy options that focus on different environmental pressures from shipping were assessed. They were evaluated based on a developed multidimensional assessment framework which includes eight assessment criteria: political implementability, acceptance & feasibility, scientific knowledge & uncertainty, technological & innovation potential, environmental and health outcomes, efficiency, distributional effects, synergies & trade-offs. The result is a semi-quantitative and participatory multi-criteria assessment. The assessment includes different steps of stakeholder engagement, such as stakeholder workshops and a web-survey, in which two of the eight assessment criteria were evaluated directly by stakeholders. The highest ranked policy option is an option targeting very specifically on the reduction of two related pressures (copper release in the water and non-indigenous species). Four of five options ranked two to six are related to a fuel switch to electricity, LNG or renewables (in ports or at sea). On the lower end of the ranking, the underwater noise related measures and the 'promoting of vessel scrapping' are evaluated.

The interaction of BONUS SHEBA with external groups on different levels of complexity was organised in work package 6. External knowledge by e.g. stakeholders of the shipping and environmental sectors was accessed to support the project on the one hand, and progress and results of BONUS SHEBA were reported to the scientific community, authorities, politicians and the public by different means on the other hand. Stakeholders were assigned to the advisory board and were contacted as consultants for dedicated topics in order to support especially the scenario building process of BONUS SHEBA at several dedicated events. Among them a quantitative expert elicitation applying the Sheffield Elicitation Framework (SHELF) was conducted, addressing specific issues as e.g. the future use of LNG as fuel. Via several outreach activities the interested people from the industry, politics and the public were informed on the topics of environmental impacts of shipping generally and on the project and it progress specifically. Among them were an exhibition and a panel discussion during the Swedish politicians' week in Almedalen, Gotland, in 2016, and several contributions to the "Forschung vor Anker" events of HZG at the Baltic coast as well as seminar 'Sustainable shipping in the Baltic Sea beyond 2020', organised by BONUS SHEBA at the 8th EU Strategy for the Baltic Sea Region (EUSBSR) Annual Forum in Tallinn. A conference "Shipping and the Environment", affiliated as 2nd BONUS symposium, jointly organized by BONUS SHEBA and the project SOLAS (International Surface Ocean - Lower Atmosphere Study), brought together about 120 scientists and stakeholders of the shipping sector from all over the world. The conference organising

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committee is organising a joint special issue in Copernicus open access journals 'Atmospheric Chemistry and Physics' and 'Oceanic Science' (https://www.atmos-chem-phys.net/special_issue948.html) on the same topics, inviting both publications stemming from the conference and from the wide scientific community. To further inform the scientific community, stakeholders and the public on the results of BONUS SHEBA an information portal was designed and implemented. Also a set of educational and easy perceptible material for teachers, pupils, students and public was compiled along with an environmental manual addressing ship owners and harbour operators.

BONUS SHEBA has become a flagship project of the EUSBSR and throughout the duration of the project informed the international steering board of the EUSBSR Policy Area Ship on progress of the project at their semi-annual meetings. The project became a partner of starting-up INTERREG Clean Shipping Project Platform CSHIPP. BONUS SHEBA has also become a part of the Baltic Earth (www.baltic-earth.eu).

Main results achieved during the project

The BONUS SHEBA project has advanced the understanding of shipping related impact on the environment in the Baltic Sea Region. The holistic approach of looking at the impacts of operational shipping on atmospheric, marine and underwater noise pollution simultaneously have significantly improved the general understanding of shipping related impact, based on efficient transfer of knowledge and concepts previously applied on assessments of air pollution to assessments of marine pollution and underwater noise. The assessment framework developed in BONUS SHEBA has been implemented as far as the current state of knowledge has allowed and mapped the path towards a complete quantitative assessment.

The new capabilities for modelling of shipping-related water contaminants and underwater noise were developed and implemented into the Ship Traffic Emission Assessment Model (STEAM) setting up one of the cornerstones of assessment framework for the impacts of shipping. Prior to BONUS SHEBA the use of AIS data to assess marine pollution from shipping had only been applied to model the indirect contribution from shipping emissions through atmospheric deposition. The achievements in modelling of emissions of water contaminants is pioneering and the very first complete inventory and calculation of load factors of waste streams and the sum of pollutants from all waste streams, available for shipping. The development of underwater source module of STEAM is the first attempt to indicate the levels of noise emitted by ships, advancing our knowledge of spatio-temporal variation of shipping noise and increases general knowledge of ships as source of noise pollution. Further, a completely new model was developed to describe small boats, The Boat Emissions and Activity siMulator (BEAM) and applied to the Baltic Sea. All these developments facilitate regular annual reports of shipping-related emissions of air pollutants, water contaminants and underwater noise energy for HELCOM member states. This framework facilitates also for further developments, both in terms of expanding the regional coverage to European and global as well as in terms of updating and improving the emission factors of the different pollutants and contaminants as the new data are becoming available.

Important, yet underutilized concept in assessments of environmental pollution, is the use of scenarios linking pollution to the societal development. In this light, the work in BONUS SHEBA has been truly ground-breaking and a very good example of successful inter- and transdisciplinary work. The scenario work which formed the second cornerstone of the assessment framework advanced our understanding of impacts of the main drivers of shipping on its environmental sustainability in upcoming decades. The project produced predictions of emissions to air and water as well as of underwater noise for present time and for a number of scenarios for years 2030 and 2040 for shipping in the Baltic Sea, giving us insight to the sensitivity of the trends in emissions to the developments in shipping activities, legislation and uptake of new fuels as well as exhaust and waste cleaning technologies. The scenario predictions are consistent with emissions produced by the STEAM model and facilitate further environmental and socio-economic assessments of impacts of shipping in these scenarios.

The extensive atmospheric chemistry and coupled ocean dynamic – biogeochemistry modelling as well as the case-study of noise propagation modelling performed in BONUS SHEBA laid the third cornerstone of the framework connecting the pressures from shipping to the environmental impacts in terms of spatio-temporal distributions of concentrations of pollutants and their impacts on ecosystems. The impact of shipping has been analysed in relation to the three EU Directives; Air Quality Directive (AQD), MSFD and WFD. These analyses identified the main areas of environmental degradation caused by the shipping currently and potential improvements or lack of these in different future scenarios. They also helped to identify uncertainties and knowledge gaps in a fully quantitative assessment framework. The fourth cornerstone of the BONUS SHEBA assessment framework is the linkage from the pressures of shipping in the Baltic Sea to its effects on ecosystem services and human wellbeing and assessment of policy options with multidimensional framework. The assessments developed in BONUS SHEBA have been used by several national agencies for evaluations of the environmental goals and are timely for the upcoming update of the Baltic Sea Action Plan as recognised at the 18th meeting of the HELCOM Maritime Working Group in Hamburg in September 2018. The developments in assessment of underwater noise from shipping were recognised by HELCOM.

The continuity plan of the project

There are two aspects of the continuity of the project. One is that the results are publicly available after the project end. This will be facilitated through the BONUS SHEBA information portal hosted by coastMap (a marine Geoportal of the Institute of Coastal Research, Germany) which will be opened in December 2018. The second aspect is continuation of the research and application of the results achieved by BONUS SHEBA to support the stakeholders of the shipping sector. Throughout the project duration the BONUS SHEBA consortium has been involved widely in collaboration with other research projects and with stakeholders at national, macro-regional and international levels which facilitates for a number of continuity actions in this direction. The developments achieved in the STEAM model will be used in regular annual reports of shipping-related emissions of air pollutants, water contaminants and underwater noise energy for the HELCOM member states. The assessments developed in BONUS SHEBA have been already utilised by several national authorities for evaluation of national environmental goals and strategies and several national activities involving one or several BONUS SHEBA partners have been started. As a flagship of the EUSBSR Policy Area Ship BONUS SHEBA became part of the Interreg clean shipping platform CSHIPP facilitating further synthesis and dissemination of BONUS SHEBA outcomes along with results of other shipping projects active in the Baltic Sea region to authorities and industrial stakeholders. Several members of the consortium have been involved in H2020 research project applications which, if successful, would take the BONUS SHEBA achievements to European and global levels.

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