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ORIGINAL ARTICLE

Shared socio-economic pathways extended for the Baltic Sea: exploring long-term environmental problems

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Abstract

Long-term scenario analyses can be powerful tools to explore plausible futures of human development under changing environmental, social, and economic conditions and to evaluate implications of different approaches to reduce pollution and resource overuse. Vulnerable ecosystems like the Baltic Sea in North-Eastern Europe tend to be under pressure from multiple, interacting anthropogenic drivers both related to the local scale (e.g. land use change) and the global scale (e.g. climate change). There is currently a lack of scenarios supporting policy-making that systematically explore how global and regional developments could concurrently impact the Baltic Sea region. Here, we present five narratives for future development in the Baltic Sea region, consistent with the global Shared Socioeconomic Pathways (SSPs) developed for climate research. We focus on agriculture, wastewater treatment, fisheries, shipping, and atmospheric deposition, which all represent major pressures on the Baltic Sea. While we find strong links between the global pathways and regional pressures, we also conclude that each pathway may very well be the host of different sectoral developments, which in turn may have different impacts on the ecosystem state. The extended SSP narratives for the Baltic Sea region are intended as a description of sectoral developments at regional scale that enable detailed scenario analysis and discussions across different sectors and disciplines, but within a common context. In addition, the extended SSPs can readily be combined with climate pathways for integrated scenario analysis of regional environmental problems.

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Introduction

Scenario analyses in support of environmental assessments have evolved rapidly over the past 20 years in response to the challenges of sustainable development and the growing recognition of the urgency to act now while planning actions for the medium to long-term despite uncertainties about future developments (Alcamo 2001; Moss et al. 2010; Shell 2013, 2008). Scenario analysis can be a powerful approach to explore plausible futures of human development under conditions of environmental, social, and economic change and uncertainty. In addition, it can help in learning and assessing how the environment responds to human activities, to evaluate implications of different approaches to reduce pollution and resource overuse, and to adapt to altered environmental conditions. This may be particularly important where vulnerable ecosystems are at stake.

The Baltic Sea is such a fragile ecosystem, vulnerable due to a combination of natural conditions (shallow and semi-enclosed) and multiple, interacting anthropogenic pressures including the direct and indirect effects of climate change, eutrophication, pollution, overfishing, invasive species, shipping, and habitat destruction (BalticSTERN 2013). In addition, the marine system is characterised by significant time lags due to repository capacity of nutrients and pollutants. These conditions and pressures have over many decades led to levels of warming, nutrient pollution, and deoxygenation that most other coastal areas around the world will experience only in the far future (Reusch et al. 2018). Despite the success of the Baltic Sea Action Plan (BSAP) since the 1990s to reduce nutrient loads to the Baltic Sea (Gustafsson et al. 2012), the current loading (phosphorus (P) in particular) far exceeds the targeted level (Helcom 2015).

The inertia in the Baltic marine system means that for society to meet the maximum nutrient load targets, and gradually to retain the good environmental status of the sea, it is essential to consider long time horizons. It will therefore necessitate a long-term planning that takes into account the complex interactions between human society, climate, and the marine environment under large uncertainties of how society and climate may evolve in the long term.

Previous studies on key environmental problems of the Baltic Sea have incorporated downscaled impacts of climate change on natural processes (BACC II Author Team 2015; Niiranen et al. 2013), but have so far made use of disparate assumptions of drivers and pressures without a comprehensive and harmonised set of societal pathways to combine climate impacts with direct societal pressures on the Baltic Sea ecosystem. Previous detailed assumptions on direct anthropogenic changes in nutrient loading to the Baltic Sea (e.g. Omstedt et al. 2012; Gustafsson et al. 2011; Humborg et al. 2007; Wulff et al. 2007) were developed without considering different possible and internally consistent socioeconomic developments. Also, they were not harmonised with greenhouse gas and aerosol emission scenarios.

To effectively alleviate multiple pressures on the Baltic Sea and adapt to changed environmental conditions, policy-makers and stakeholders in the boundary countries can benefit from a systematic exploration of plausible future drivers and pressures on the marine environment. A useful approach to deal with uncertainties about future developments in a highly complex system is the development and analysis of regional scenarios. Also, the integrated assessment modelling community and other researchers focusing on the Baltic Sea environment can benefit from a set of regional internally consistent narratives that are aligned with global pathways for discussion and model-based assessments to explore future developments and challenges. This can be achieved by developing plausible and internally consistent pathways for the economic sectors and consumer segments that are responsible for the extractive and polluting uses of the sea. As many interactions and feedbacks in socioecological systems, such as in the Baltic Sea region, play out over the temporal scale (i.e. past, present, and future context) and geographical scale (i.e. local, regional, and global scale), it is necessary to address such processes from a multi-scale perspective (Zurek and Henrichs 2007). For instance, the environmental performance of economic sectors in the Baltic Sea region such as those in charge of nutrient emissions (agriculture, wastewater treatment), fisheries (food industries, recreation) as well as marine traffic (tourism, transportation) are heavily driven by global drivers such as global markets, technological development, consumption patterns, and birth rates. Combined with the inertia of the Baltic marine system and its vulnerability towards climate change, it is highly relevant to link to or nest regional Baltic environmental scenarios within well-established global scenarios that apply a long time horizon, such as the global Shared Socioeconomic Pathways (SSPs) applied in the new scenario framework for climate research.

The SSPs are an integral part of the new climate scenario framework (Moss et al. 2010; O'Neill et al. 2017) aiming primarily to provide a basis for integrating research on climate change mitigation and adaptation. However, the SSPs can also be applied to the analysis of broader sustainability development contexts without necessarily referring to climate mitigation and adaptation challenges. This is because the socioeconomic challenges to climate mitigation and adaptation are closely linked to different degrees of socioeconomic development and sustainability (O'Neill et al. 2017). In addition, the relatively broad formulations of the global SSPs make them flexible to extend to different scales, sectors, and environmental problems (van Vuuren et al. 2014).

A body of literature has recently emerged that extends global SSPs to sectors not explicitly included in the SSP narratives. For example, SSPs have been extended to study future land use and its consequences on food provision and greenhouse gas emissions (Popp et al. 2017; Riahi et al. 2017), water demand (Mouratiadou et al. 2016), energy supply and its emissions (Bauer et al. 2017), and air pollution (S. Rao et al. 2017). There are also emerging studies exploring more narrowly specified economic sectors such as skipjack tuna fishing (e.g. Dueri et al. 2016). Another important recent development is the extension of SSPs at finer spatial scales to allow for more local studies in climate research. This includes for instance the extension of SSPs to the European scale (Kok et al. 2018), to the scale of the Barents' region (Nilsson et al. 2017), to the U.S. Southwest focusing on agriculture, water, and energy sectors (Absar and Preston 2015), and to the scale of West Africa focusing on the future of agriculture and food security (Palazzo et al. 2017).

Different concepts and methods exist with regard to extending global narratives to regions and sectors relating to multi-scale linkages, scenario development processes, and internal consistency in storylines across scales. Zurek and Henrichs (2007) provide concepts for thinking about linkages of scenario elements across geographical scales according to the degree of interconnectedness and the type of scenario development process followed. Kok et al. (2018) proposes an operationalisation of one of these concepts—equivalent across scales—applied to four SSPs at European scale, where outcomes were directly transferred between scales, whilst consistent and where possible coherent with another set of existing socioeconomic scenarios for Europe.

Nilsson et al. (2017) proposes a scenario development process that combines a top-down approach, using the SSP framework as the boundary conditions for global change, with participatory bottom-up approaches to generate locally relevant scenarios for planning climate adaptation. The participatory bottom-up process identified and ranked locally relevant drivers of change before nesting these within the global SSP narratives based on workshop participants' discussions of how local drivers could play out at regional level in different futures captured by the global SSPs. To ensure systematic linking of qualitative elements of scenarios with internal consistency across scales, novel methods have been proposed such as the factor-actor-sector approach (Kok et al. 2006; Absar and Preston 2015) and the linked cross impact balances analysis (Schweizer and Kurniawan 2016). Internally validating multi-scale scenarios can also rely on 'soft links', i.e. through the use of interpretive arguments of the degree of linkages of scenario elements (Zurek and Henrichs 2007).

The objectives of this paper are twofold. Firstly, we aim to present and evaluate a new method that operationalises the development of regional environmental scenarios that are coherent with the global SSPs. Secondly, we present resulting regional storylines for the Baltic Sea region that can be used as a harmonised set of scenarios with enough sectoral detail to serve the purposes of studying plausible future trends of eutrophication, fisheries, and marine traffic in the Baltic Sea for use in further integrated assessments and cost-benefit analysis.

The article is organised as follows: "Methodology" section describes the chosen methodology for extending global SSPs to regional and sectoral level; "Background to the case study—the Baltic Sea Region" section provides the background to the Baltic Sea case study; and "Results" section provides the summary of Baltic Sea regional narratives by sectors with Supplementary Material 2 containing the full narrative description. Finally, "Discussion and Conclusions" section discusses the applicability and challenges of extending global SSPs to specific regional sectors for integrated environmental assessments.

Methodology

The SSP narratives have been designed to span different combinations of future socioeconomic challenges that make mitigation and adaptation to global climate change either hard or easy (see Fig. 1) (O'Neill et al. 2014).

Figure 1 left hand side illustrates the challenge space between mitigation and adaptation to climate change in a global context (O'Neill et al. 2014). A similar outcome space can be developed to span regional futures by replacing the axes with challenges to mitigate and adapt to the specific regional problems. The relative positions of the various SSPs in the new challenge space is unique to the region and the particular problems studied. Global SSP narratives that pose substantial challenges to manage global climate change may cause only small challenges to managing regional environmental problems, and vice versa. Therefore, the SSP narratives need to be re-interpreted in a regional context, since many regional problems such as eutrophication of semi-enclosed marine areas can be effectively mitigated by locally implemented measures.

Figure 1, right hand side illustrates the position of the SSPs with regard to Baltic Sea environmental problems. The placements are based on our initial assessment (see "Discussion and Conclusions") which also serves to illustrate that placement at different scales does not have to be equal to the global position when extending the SSPs for environmental change research.

We apply a combined top-down bottom-up approach to extending SSPs to the Baltic Sea for environmental change analysis. We extend the global SSP scenarios to the Baltic Sea region using the 'soft' linkage approach proposed by Zurek

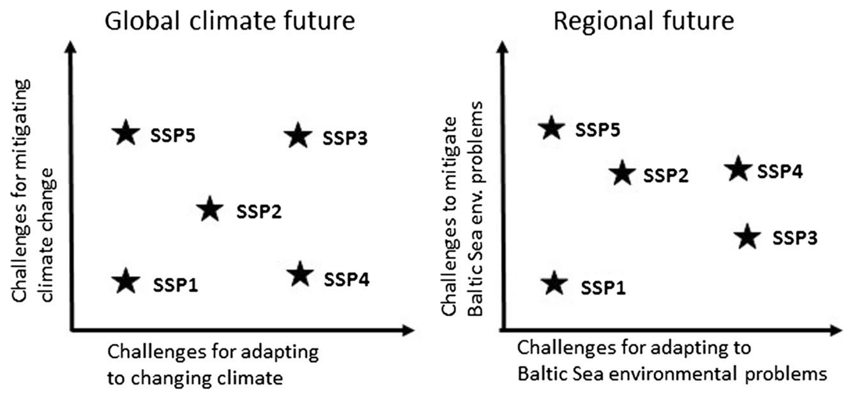

Fig. 1 Socioeconomic challenges to combat global climate change and regional environmental problems in the Baltic Sea (adapted from O'Neill et al. (2014) and initial assessment)

and Henrichs (2007) and make use of the DPSIR framework (Thomas 1995) to enable a systematic exploration of how complex interactions of multiple human drivers may impact the Baltic Sea ecosystem in the medium and long term under changing societal developments. The coupling of the regional scenario development process follows a consecutive approach (Zurek and Henrichs 2007) that uses the existing global SSP scenarios as boundary conditions for developing extended regional SSPs for key sectors causing main impacts on the Baltic Sea condition. The identification and description of regional drivers of change relevant to the Baltic Sea and how these link with global scale drivers for the individual SSPs is based on a deliberative cross-disciplinary expert workshop. Specifically, we ensured that the identification of regional drivers was made dependent of the global narratives, while the co-construction of the narratives was coherent across scales. The following section explains our approach.

Approach to extending global SSPs to regional environmental change research

Addressing scale-consecutive scenario development process with a soft linkage across scales

We chose a consecutive scenario development process (Zurek and Henrichs 2007) to achieve a high degree of linkage and consistency across scales, where readily available global SPP scenarios and the supporting quantitative projections provide the boundary conditions for the Baltic Sea scale narratives (see "Causality of drivers and pressures" section).

We apply a 'soft' linkage approach between the global and regional scale (Zurek and Henrichs 2007) to allow for the extension to sectors and regulatory settings, which are not explicitly described at global scale, but relevant for analysing broader environmental change issues. The 'soft' linkage approach between the global and the regional scale covers three distinct degrees of linking scenario elements: consistent, coherent, and comparable across scales. In a consistent way of linking across scales, the 'higher scale scenarios provide strict boundary conditions for lower scale scenarios' (Zurek and Henrichs 2007), meaning that the main assumptions on drivers and scenario logics play out in similar ways at global and regional scale. In a coherent linkage between scales, scenario logics are transferred from the global to the regional scale. It explores what would happen at the regional scale if decision-makers use a similar logic or way of thinking as that which plays out at the global level. In a comparable linkage between regional and global scales, the link between scales is very loose with scenarios across scales connected mainly by the issue they address and not strictly cohering with the scenario logics or main trends of the global scale scenario.

We chose the coherent approach as it allows to think through what implications global drivers and trends could have for sectors and activities that cause the main pressures on the Baltic Sea, but which are not explicitly included in the global SSPs. This would also allow for quite different scenario outcomes at regional scale without jeopardising the underlying ideas about the future world given by the global SSPs.

Causality of drivers and pressures

We applied the DPSIR framework definition of drivers and pressures to enable a systematic exploration of how complex interaction effects of multiple human pressures may impact the Baltic Sea ecosystem in the medium and long term under changing societal developments (Thomas 1995; Antunes and Santos 1999; Holman et al. 2005; Oesterwind et al. 2016). We distinguish between drivers given by the global SSPs (i.e. population and urbanisation trends, economy and lifestyle, international trade, technology development, policies and institutions, environmental policies and regulation, land use and energy production, described in Table ESM1) and drivers at the regional level. Regional level drivers are further divided into primary and secondary. Primary regional drivers are regionalised/national versions of the global drivers and drive the development of regional sectors (secondary regional drivers) such as fisheries and agriculture. The secondary drivers (i.e. sectors/activities) directly cause pressures or state changes on the Baltic Sea through extractive uses and emissions of pollutants that exceed the limits of the ecosystem.

First, prior to the scenario workshop, we scale global drivers to primary regional drivers. Global trends in terms of economy and lifestyles, attitudes and values of society towards nature and natural resources, policies, and institutions, and the way in which society is generally organised are described by O'Neill et al. (2017) and for Europe by Kok et al. (2015). These trends influence how future societies will utilise resources and services provided by the Baltic Sea as well as the use of the marine environment as a recipient of pollution, e.g. through land use change and fisheries. Key quantified global drivers, at country or global levels, add to the basic elements of the SSPs. These include population and urbanisation (Jiang and O'Neill 2017; Samir and Lutz 2017), economic and technological development (Crespo 2017; Leimbach et al. 2017; Dellink et al. 2017), and level of international trade (O'Neill et al. 2017; Popp et al. 2017; van Vuuren and Carter 2014). These basic elements have previously been analysed in integrated assessment models for energy and land use implications (Bauer et al. 2017), air pollution (S. Rao et al. 2017), and land use change based on population changes and demand for food and non-food products (Popp et al. 2017). ESM1 summarises the key global drivers of anthropogenic disturbance affecting the Baltic Sea marine ecosystem and the linkage to the region.

Second, we use a participatory approach to identify and describe regional (primary and secondary) drivers for major pressures on the Baltic Sea and describe how global socioeconomic developments are likely to affect these (see "World café deliberation" section).

We operationalise this process through a cubic representation of needed narrative elements, capturing both the multiple impacts of global and regional primary drivers (SSPs) on a number of regional sectors (secondary drivers) and multiple pressures of sectors on the marine environment (pressure/state change—e.g. the 11 GES descriptors of the EU Marine Strategy Framework Directive[1]) (see Fig. 2). The top-down and bottom-up approach aims to populate the individual cells.

Process to extend global SSPs to regional environmental change research

Process of co-creating extended SSPs for the Baltic Sea region

In order to elicit key regional storyline elements, a deliberative cross-disciplinary expert workshop was organised using the world café format (Schieffer et al. 2004) to facilitate large group discussions and to link ideas within a larger group and access collective intelligence. The workshop was open to researchers working with the Baltic Sea region environment and other interested stakeholders, here defined as those involved

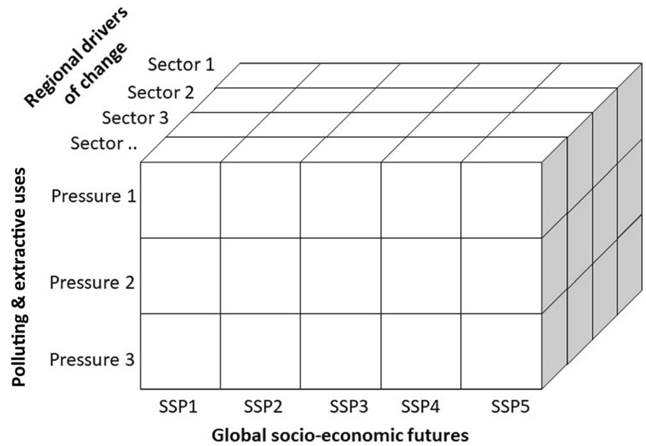

Fig. 2 Overarching structure capturing both the multiple impacts of global and regional primary drivers (SSPs) on a number of sectors (secondary regional drivers), and multiple pressures of sectors on the marine environment (pressure/state change)

in the management of the ecosystem in the region. The workshop was co-organised by the BONUS secretariat and the BONUS BALTICAPP project as a clustering activity and was advertised through the BONUS secretariat's web[2] and a large list of stakeholders including NGOs, think tanks, research financing organisations, and research networks in the Baltic Sea region and European level. It gathered 33 scientists, funding managers, and policy-makers over 2 days. Expertise represented in the group included agronomy, fishery, shipping, oceanography, hydrology, ecology, economics and social science, climate change, global outlooks, and policy advice in the fields of marine spatial planning, climate change, and policy integration.

To ensure a consecutive process of coupling scenarios at different spatial scales, participants received prior to the workshop a comprehensive background material, which was also presented at the beginning of the workshop. The background material is available from (Hyytiäinen et al. 2016). The workshop started with presentations of the global SSPs and regional quantifications of population, economic growth, land use, and urbanisation changes (IIASA draft SSP database[3]) to familiarise participants with boundary conditions and the underlying scenario framework. The workshop also included some expert presentations on reflections of global outlooks and future climate projections for the Baltic Sea region taking a perspective of water quality and the marine food chain to widen the perspective of scenarios and their use for impact assessments. The world café approach where all the experts contributed to the narratives of all three sectors (three circulating groups) also aimed at ensuring consistency *internally* across sectors and SSPs.

[1] http://ec.europa.eu/environment/marine/good-environmental-status/index_en.htm

[2] https://www.bonusportal.org/events/events_archive/bonus_pilot_workshop_on_scenarios

[3] http://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/SSP_Scenario_Database.html (version 1.1, 2016)

World café deliberation

In order to steer the workshop process, participants were asked to consider and deliberate with regard to specific pressures/state changes, what future drivers may influence the Baltic Sea environment in the medium to long term horizon within each of the global SSPs, and how are global socio-economic developments likely to affect these?

The participants were divided in three interdisciplinary groups and invited into a world café process that took place both days. Each group started discussion on one of three predetermined pressures/state changes, facilitated by two researchers. For each of the pressure/state change themes, participants were asked to (i) identify and elaborate on main regional primary and secondary drivers of change and how these would differ across the SSPs; (ii) discuss how numerical projections of future developments in, e.g. economy and population would affect these drivers; and (iii) agree on verbal elements in the storylines relevant for the Baltic Sea region. After the first discussion session, the group moved to another theme and continued from where the previous group had stopped. After the third discussion round, all groups had discussed the three predetermined topics, and the facilitators put the discussion together and presented the ideas in plenary for information and further discussion. The predetermined themes of pressures or state changes were eutrophication, risks of marine traffic, and biodiversity with emphasis on fish and fisheries. These were selected based on the interests of participants and identified via a questionnaire to all the ongoing BONUS projects during the planning phase up to the workshop.

Drafting the extended Baltic Sea SSPs

The procedures, notes from the discussion groups, and a first write up of the narratives were reported in the workshop report by the researchers engaged in running the workshop (Hyytiäinen et al. 2016). Interested workshop participants were invited to continue the efforts to craft and refine the extended SSP narratives in close collaboration with the BalticAPP research team.

First, we finalised the identification of linkages between primary and secondary drivers. Policies and regulations play here a key role in shaping the footprint of sectors on the marine environment. Current environmental policies and regulations of relevance as primary regional drivers include the EU Directives: Water Framework Directive (WFD), Marine Strategy Framework Directive (MSFD), National Emissions Ceiling Directive (NEC), Birds Directive, and Habitats Directive, and the following EU and international programmes, policies, and agreements: the Baltic Sea Action Plan (BSAP), Gothenburg Protocol on air pollution,[4] the Common Fishing Policy (CFP), the Common Agricultural Policy (CAP), the International Convention for the Prevention of Pollution from Ships (MARPOL), and the International Convention for the Control and Management of Ship's Ballast Water and Sediments (BWM Convention) regulating environmental aspects of shipping via the International Maritime Organisation (IMO).

Second, we formulated the causal linkages between secondary drivers (sectors) and pressures/state changes of the Baltic Sea and, where relevant, took previous literature on environmental scenarios into account: Agriculture impacts the Baltic Sea through leaching and runoff of N and P from agricultural land and ammonia volatilisation from manures and fertilisers, which is deposited on land and sea. Land use, cropping systems, livestock, and management practices directly impact the level and location of nutrient loadings (Hashemi et al. 2016), which in turn reflect dietary choice, population, and trade flows in agricultural produce. For Europe, Westhoek et al. (2014) investigated different scenarios of dietary changes and associated impacts on livestocks, agricultural land and emissions. Pressures from *WWTPs* is directly determined by the population numbers connected to different levels of treatments (from tertiary to primary), urbanisation, dietary choice and the level of treatment efficiency. WWTPs add to nutrient loading to the Baltic Sea. Previous work has extended SSP1 and SSP3 to the sewage sector at global scale (Hofstra and Vermeulen 2016; van Puijenbroek et al. 2015). Atmospheric deposition of nitrogen oxides originates from combustion processes from transport and energy production and emissions, and belong to the group of long-range transboundary air pollution substances regulated by the Gothenburg Protocol. Ammonia emissions from agricultural activities have previously been described in four scenarios for the twenty-first century based on the SRES scenarios (Bodirsky et al. 2012). These emissions are predominantly regional and depend on the scale and location of livestock operations and regulations to reduce ammonia volatilisation. Commercial fisheries (targeting mainly cod, sprat, herring, salmon, and flatfish) can pursue different strategies ranging from sustainable fisheries to maximising short-term economic gains and are organised from large-scale high-tech fishing vessels to traditional small-scale fishery. Fishing efforts affect the balance and structure of fish stocks, which are key components of biodiversity in the Baltic Sea. Previous work has analysed outcomes of different fisheries strategies on global skipjack tuna fisheries under one particular SSP (Dueri et al. 2016). Regional integrated scenarios including a detailed analysis of fisheries have been developed by Pinnegar et al. (2006), but these were not based on or linked to global narratives. Shipping impacts the sea through air pollution, oil spills (accidents or allowed), as a vector for invasive species (hull and ballast water), through emissions of sewage and waste, and with toxic substances from hull paint. The Baltic Sea today is recognised by the IMO as a sensitive marine area

[4] Protocol to Abate Acidification, Eutrophication and Ground-level Ozone

and has more stringent limit values for air pollution; restrictions on antifouling paint; a special status forbidding sewage water emissions from passenger vessels in the future; and special equipment requirements for ships to reduce risks of accidents. Future shipping volumes and emissions have been estimated by Smith et al. (2014).

Third, we refined and complemented the regional extended narratives formulated during the world café process. The workshop deliberations provided identification of drivers as well as directions and variations between SSPs with respect to primary regional drivers and how these would translate into pressures from the secondary regional drivers (sectors).

Background to the case study—the Baltic Sea region

The Baltic Sea, situated in northern Europe, is a semi-enclosed sea with a catchment area four times larger than the surface of the Baltic Sea. Nine countries share the coastline,[5] of which eight are part of the European Union. Close to 85 million people live within the catchment area in 14 countries (Nilsson et al. 2017) with two relatively distinct economic conditions: GDP per capita in the former Eastern bloc countries is almost half of that in the four countries that have a longer tradition for liberal economies and democracy. The catchment area is characterised by the densely populated and industrial south with agriculture as the dominating land cover in a temperate climate. In contrast, the north has a boreal climate and is overall rural with some agriculture but dominated by forests. Agriculture varies greatly across the Baltic Sea drainage basin in farm type, farm size, areal extent, and crop and livestock intensity (Andersen et al. 2016). Agricultural production is intensive with both arable crop and livestock in Denmark, Germany, Southern Sweden, and parts of Southern Finland with agriculture accounting up to 60% of the land area and farms typically larger than 100 ha, producing for the European and global markets. The agricultural production in Poland, Belarus, and the Baltic states is less intensive, but typically with small farms less than 10 ha. These farms mainly produce for the domestic markets. The northern parts of the drainage basin in Sweden, Finland, and Russia have much less agriculture and the agricultural production is largely based on extensive grassland-based cattle and sheep farming, often with dairy production, but mostly for the local markets. Gradients in the Baltic Sea also follows grossly the north–south axis: a strong salinity gradient from almost fresh water in the north to close to oceanic salinities at the North Sea border cause a strong structural constrain on the ecology. The gradient in anthropogenic pressures in combination with hydrodynamic constrains results in a eutrophication gradient, where the northern parts are significantly less eutrophic than central and southern parts. Fishery is primarily focused in the southern part for cod and central and north parts for sprat and herring, partly because population distribution but partly also because the commercially important stocks are restrained by the hydrographic conditions.

The external nutrient loads to the Baltic Sea increased until the mid-1980s. Thereafter, both N and P loads to the sea have been in a declining trend. Increased environmental awareness since the 1970s motivated the design and adoption of effective policies and consequent investments and technological development in treatment technologies in industrial outlets and municipal wastewater treatment plants (WWTPs). Some countries (e.g. Finland, Denmark, and Sweden) improved the performance of their WWTPs already in the 1970s, 1980s, and early 1990s, while other countries (e.g. Poland, the Baltic States, and Russia) upgraded their WWTPs later and many of these countries still lag behind in their progress (Helcom 2015, Eurostat 2018). Despite the advancements, the current nutrient loads are still far too large: for example, N and P loads to the major basin Baltic Proper need to be reduced by 13% and 50%, respectively, in order to reach the Baltic Sea Action Plan targets jointly agreed by the HELCOM countries (Svendsen et al. 2015). Especially for P, significant legacy effects in the catchment is expected between measures and effect on diffuse loads to the sea (Mccrackin et al. 2018). In addition to delays in the catchment, the Baltic Sea is a slow coastal system with i.a. a turn-over time of the total freshwater supply of about 30 years (Stigebrandt and Gustafsson 2003), and a long-term repository capacity of nutrients of 10 to 50 years (Gustafsson et al. 2017). Despite this, there are signs of improvement regionally in response to nutrient load reductions (Andersen et al. 2017). Fish stocks are under pressure from eutrophication, but also strongly driven by fishery and inter-species population dynamics. Apart from the Kattegat area where a regime shift was observed in the food web due to nutrient reductions, no clear signs of improvements on fish stocks are observable in the Baltic Sea (Lindegren et al. 2012).

The Baltic Sea is also an area with very intense shipping activities; it is a major export route for Russian oil products and intense passenger traffic in addition to container, bulk, and general cargo ships. Pressures include nutrient loads, mainly from NO_X emissions, copper and other substances from hull paint, and in the future potentially substances emitted with scrubber water. In addition, there are risks associated with international shipping mainly in the form of accidents leading to oil-spill and the introduction of alien species via ballast water or hulls. Strict restrictions on discharge into the sea of oil or oily mixtures, sewage from passenger ships, and garbage are in place today. Further, the Baltic Sea is a sulphur emission control area with stricter limits on the allowed fuel sulphur content than in other sea areas and stricter limits on

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

NOx emissions will be implemented for new ships from 2021 (HELCOM 2018).

Results

Lessons from the co-creation process

For the co-creation process, we targeted experts working on issues relating to the Baltic Sea environment and stakeholders from the region and Europe engaged in the management of marine areas. Those interested were invited to continue after the workshop together with the organising research team to refine and craft the narratives. The workshop approach proved successful, as it integrated knowledge from a 'high-level' group of Baltic Sea experts and stakeholders representing different scientific fields and sectors based on their long-term scientific work and expertise. The possibility to contribute to the long-term writing process in addition to the 2-day workshop improved the end-result, as there was a possibility to elaborate the issues and accumulate a large amount of knowledge to build the narratives. Three experienced scientists who are experts in the respective fields of the group work facilitated each of the three rotating groups, which also secured the internal causal validity of links between drivers and effects/state change. The main building blocks were laid during the first round of deliberations in each of the three groups. This largely determined discussions and deliberations of the following rotating groups. During the second round of deliberations, groups knew the process and could discuss the drivers-effect links on a new topic, but with the former topic in mind. By the third round, all participants had contributed, supplemented, and commented on the narratives of all three themes. This was one way to make sure that the narratives were internally consistent. For instance, that the narratives for maritime traffic are consistent with the narrative for nutrient loading.

Narratives for the Baltic Sea region

The narratives focus on the primary and secondary regional drivers of three major pressures in the Baltic Sea: (i) Water borne nutrient loads from agriculture and wastewater treatment plants (WWTPs), and atmospheric nitrogen (N) emissions from agriculture, transport, and industrial combustion; (ii) commercial fishing, and (iii) shipping. Table 1 summarises the regional narratives describing the different future developments of how globally coherent, regional drivers of pressures on the Baltic Sea may develop by sector. The full narrative text is provided in ESM2, presented in a structure describing first the primary regional drivers (General social trends), followed by description of secondary regional drivers (nutrients from agriculture, WWTPs and atmospheric deposition of nitrogen; shipping; and fishing).

Discussion and conclusions

New method to develop regional environmental scenarios

This study provides one of the first regional studies that systematically interprets the global SSPs for assessing complex regional environmental problems, where climate change is one of multiple pressures amongst others. The aim of the regional narratives has been to provide a consistent and long-term context for communicating, debating, and analysing a plausible range of long-term futures that will affect the state of the Baltic Sea with different outcomes. The combination of top-down bottom-up approaches has recently been applied in extending global SSPs to local scale by (Nilsson et al. 2017) for climate adaptation research. In contrast to how they used the SSPs in a participatory scenario process, we actively used the global SSPs and associated IIASA SSP database information to inform our expert/stakeholder group of the starting point for the regional scenarios. This top-down approach of starting with the SSPs can have the drawback of limiting the freedom of a participatory scenario process. Because our objective of developing the regional narratives is for broader environmental change analysis, we introduced a hierarchy of regional drivers. Primary drivers relate to general societal trends that are fully consistent with the global SSP drivers and to a large extent provided by the IIASA SSP database at national or regional scale. Secondary drivers relate to how these regional societal trends could play out in the sectors/activities that cause main pressures on the Baltic Sea environment. At this level of secondary drivers, the participatory scenario process had a larger degree of freedom. Following the proposal of Zurek and Henrichs (2007), this corresponds to the multi-scale linkage approach called coherent across scales. The world café set up with three rotating groups played a central role in ensuring consistency between scales and between sectors within each SSPs.

Regional conditions and sectoral activity levels may thus deviate from the global SSPs. An example is the regional rivalry pathway (SSP3). While at a global level, agricultural area would expand significantly due to lower agricultural productivity, strong population growth, and limited agricultural trade flows (Popp et al. 2017); the Baltic Sea region could be self-sufficient with food and fodder and still reduce agricultural production because of its current trade surplus in agricultural produce and a strong population decline in SSP3 for this region. The subsequent pressure from agriculture would reduce significantly and hence improve the environmental condition—at least when considering this sector separately (see Fig. 1). O'Neill et al. (2017) further reflect on the effectiveness of using global pathways as a basis for developing regional trends and argue that in the case of a weak connection

Table 1 Summary of regional narratives

Regional drivers	SSP1	SSP2	SSP3	SSP4	SSP5
General social trends	Full implementation of EU Directives; strong environmental regulation; and diet changes towards more plant-based, local food. Dense, rapid urbanisation	Partial implementation of EU Directives; some improvements in environmental performance; moderate urbanisation; and food consumption relatively stable	Break down of EU policy framework and HELCOM; national subsidy schemes support food and energy security; reduced environmental performance; slow urbanisation; and decreasing population in the region	Partial implementation of EU Directives; focus on local environment near high income areas; and demand by global elite increase for meat and dairy	Change in environmental regulation towards relative targets; rapid technical development with some environmental improvements; increased demand and export of animal products; and expansive, rapid urbanisation
Livestock production and agri. land use	Contraction	Stable	Contraction	Expansion	Expansion
Agricultural regulation	Subsidies in place to counter market failures and enhance multiple ecosystem services	Subsidies in place to enhance productivity; less focus on environmental performance	Break down of common agricultural policy; focus on self-sufficiency	Sub-national agricultural regulation	World market driven; focus on increasing productivity
Land management	Smart agriculture; productivity increases; increased N and P efficiencies; strong livestock reduction; and decrease in exports and imports of animal related products	Larger units and increased industrialisation and production efficiency; some efforts to increase N and P efficiencies; increase in livestock; and increase in exports and imports of animal related products	Focus on self-sufficiency; reduced N and P efficiencies; ageing of farm equipment and lack of investments in new technologies; and farm restructuration towards larger and more efficient units is reversed	Focus on high productivity in large-scale farms; pockets of small-scale low-productive farming; reduced N and P efficiencies; and increase in exports of animal products.	Smart agriculture; productivity increases; reduced N and P efficiencies; increase in production and export of animal products; and increase in imports of fodder
Fish demand	Mainly for local consumption, moderate amounts for use as fishmeal in low-impact aquaculture locally and for export	Amount of fish caught for human consumption slightly decreases, amount for feed slightly increases. Fish used both within the region and in global trade	Fish products traded within ‘blocs’ only, as human food or as feed for aquaculture. In general, decreased demand because of falling population. Lack of capital to invest in aquaculture development	Mostly for aquaculture, both used locally and as export, some local consumption	Almost exclusively as aquaculture feed, both used locally and as export
Fishing management	Sustainable ecosystem-based management; small-scale fishing increases	Sub-optimal management with very little ecosystem considerations	No coordination of fishing activities; no or only a small group of countries apply regulations; in case of military tensions fishing strongly reduced	Highly exploitative, reactive, and inconsistent management; fishing ceases when it becomes unprofitable and quickly starts again as stocks recover; fishing pressure heterogeneous in space and time; and some illegal subsistence fishing by poor	Coordinated industrial exploitation focusing on short-term gains; regulations only enforced when targeted stocks close to collapse
Shipping	Decrease; environmentally safer shipping; increase recreational sailing and transport; risk of accidents increases but	Increase; lenient regulations; increase recreational sailing; and risk of accidents increases	Decrease; decrease in touristic transportation (ferries and cruises); low safety and environmental quality; and decrease in trade	Increase; partial implementation only; no new environmental regulations	Increase; Increase in touristic transportation; high safety but no focus on environmental performance; and

Table 1 (continued)

Regional drivers	SSP1	SSP2	SSP3	SSP4	SSP5
	abated through technological advances; and stringent regulations		generally, but increase in fossil fuel trade		strong increase in trade and risk of accidents, but largely abated through technological advances
Wastewater treatment	Existing primary and secondary wastewater facilities gradually updated to tertiary; improved treatment of tertiary plants; separate lines built for wastewater and storm water runoff; and advanced onsite treatment more common in rural areas	New investment in treatment technology and expansion of sewage systems in most densely populated areas. Advanced onsite treatment remains rare	No investment to expand sewage system or to increase advanced onsite treatment. Treatment level of existing plants decline	Densely populated and wealthy regions make use of improved cleansing technology. Focus on investment that have fast and visible impact on environmental quality	New facilities are built and the sewage systems are expanded to serve expanding urban areas. No active effort to improve treatment level of existing plants

between local impacts and global pathways, the global narratives can be useful in deciding which local assumptions to make.

SSP storylines for the Baltic Sea region

The global socioeconomic narratives are broad enough to allow for multiple credible interpretations when extended at smaller spatial scales or to specific sectors. For example, the fragmented world narrative (SSP3) leaves the composition of the blocs open (individual countries vs. groups of countries). In this paper, we interpret SSP3 such that several sub-regional blocs in the Baltic Sea region are formed, for instance, with Germany striving for increased political integration with the founding countries of the EU, the Nordic, and the Baltic countries forming a loose coalition while Poland and Russia follow their own agendas. Alternatively, an equally plausible interpretation could be that each of the countries focuses on domestic food and energy security, with little cooperation between them. Such choices may lead to distinct and deviating trajectories, affecting agriculture, fisheries, and shipping, and subsequently resulting environmental externalities.

Likewise, in the case of a sustainable future (SSP1), the level of pressures on the Baltic Sea could depend on the type of agriculture in place. Our suggested narrative is based on a predominantly intensively managed (organic) agriculture on a smaller area, but could also be based on a high quality agro-ecological matrix within which fragments of high diversity native vegetation can persist along with biodiversity friendly agro-ecosystems (Perfecto and Vandermeer 2010). This type of agriculture could also cater for a growing low-impact tourism. The inequality storyline (SSP4) also leaves interpretation open in terms of how the commons are governed in the long term. Would it be in the elite's interest to protect or exploit common lands or a balance of the two? What would be the spatial implications of the elite investing in the environment only in their 'own backyard'?

The direction of how sectors evolve within a storyline has large implications for the scale and location of pressures on the Baltic Sea. Developing alternative storylines within one pathway can offer additional insights into the challenge space. Also, details of how sectors across and within different countries in the Baltic Sea region develop at different speeds or in different directions would be a valuable next step. The uncertainty space of these rather generally described qualitative SSP narratives and the adjoining numerical projections determine the uncertainty space of regionally extended SPP narratives specified for the main drivers of a regional sea (Kok et al. 2018).

The SSP challenge space illustrated in Fig. 1 is useful to investigate how easy or difficult societal futures may be in terms of mitigating and adapting to environmental problems in a given ecosystem. For the Baltic Sea, our initial assessment places SSP1 and SSP5 in the same positions as the climate challenge space. The focus on strong regional environmental regulations combined with reduced agricultural land use, increased nutrient efficiencies, and sustainable fisheries in SSP1 would lead to a reduced need to both mitigate and adapt to Baltic Sea environmental problems, while in SSP5, relaxing environmental regulations, increased shipping volumes, weakened nutrient efficiencies, and increased agricultural land use as well as a profit maximising fisheries with little regard to maintaining sustainable stocks and ecosystem health would lead to high challenges to mitigate associated marine environmental problems. Strong economic growth, rapid technological development, and significant investments in human capital could, however, constrain the adaptation challenge to a relatively low level. SSP2, the baseline storyline, is situated higher up on the mitigation challenge scale compared to the general challenge space due to current difficulties to reduce pollution problems combined with a continued trend in only partially implemented environmental regulations, agriculture intensification, sub-optimal fisheries management, and a medium growth in shipping. SSP3 shows a mixed picture with reduced pressures from agriculture due to falling population numbers in the region and a collapse in international agricultural trade, but increasing loads from point sources, poor fisheries management, and increasing risk from shipping despite an overall reduction in maritime traffic. For this reason, SSP3 could reduce the mitigation challenge, but adaptation remains difficult due to reduced financial and human resources. Society in a SSP4 world could be faced with far higher challenges to mitigate to marine environmental problems than in the climate SSP challenge space, albeit not to the same extent as in SSP5. This would be caused by a strong industrialisation of agriculture and only partial implementation of nutrient management schemes, industrial scale development of aquaculture and exploitation of fish stocks, and point source pollution that is only managed in wealthy areas. Adaptation to the marine environmental problems remains challenging for the large majority of the population.

Research perspectives

In research, the same set of extended regional scenarios can be used as a common context for consistently formulating and quantifying multiple drivers and modelling pressures on the Baltic Sea along several dimensions of human impacts, e.g. fishing, agriculture, shipping, and wastewater treatment quality. By harmonising the context of plausible futures, comparability across studies increase because of transparent and consistent causal links from regional primary drivers (lifestyle, population, economic development) to regional secondary drivers and pressures. This has a potential to improve insights for researchers and improve communication with stakeholders and decision-makers (Kriegler et al. 2012; Riahi et al. 2011; van Vuuren et al. 2014).

The regional extension of the global SSPs to specific sectors in a region can be used to study future challenges and options in mitigating existing environmental problems such as eutrophication and overfishing as well as reducing the environmental risks of marine traffic, either individually or in combination. For instance, the same scenario can be used as a starting point for quantifying (i) land use change and the subsequent pressure of N and P loads to the Baltic Sea; (ii) the level and extent of wastewater treatment plants and effects on loads to the Baltic Sea; (iii) the fishing efforts, the status of target species, and fishing fleet structure and modelling the subsequent impacts on the wider marine food web; and (iv) the change in shipping activities, security, and resulting changes in risk profile. Through the use of harmonised socio-economic narratives, it is possible to assess the combined effect of multiple pressures on the Baltic Sea that are internally congruent. Quantified drivers and pressures that are scenario based can be used as input to integrated assessments to investigate how changes may develop in, e.g. nutrient loads or fishing efforts, and subsequent responses in the ecosystem, combined with uncertainty about both future climate impacts and societal developments, and what policies, measures, and actions would be needed to obtain good environmental conditions. The regional extension of the global narratives presented here is the first step in such a process.

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