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BY
IDA MARIA BONNEVIE

DISSERTATION SUBMITTED 2021

AALBORG UNIVERSITY
DENMARK

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CV

Ida Maria Bonnevie née Reiter received a BA in Social and Cultural Anthropology in 2012 from Copenhagen University in Denmark. Due to an interest for Environmental Anthropology, Urban Planning, and Geography, which increased during an Erasmus Study Exchange at St Andrews University in Scotland, she continued her BA studies with courses in Geography and Geoinformatics at Copenhagen University. Entering the world of GIS, she enrolled for a MSc in Geoinformatics from Aalborg University Copenhagen, graduating in 2016.

Educational achievements span a variety of resource management and planning topics including completing a natural resource management summer course in India, a spatial data integration internship at COWI's GIS department, a master thesis on heat patterns of Danish households in collaboration with the City of Copenhagen, and contributing to spatial planning reports on GPS-tracking of young people's travel patterns in Aalborg City.

Pre-PhD work experience includes one year of employment at the Danish Business Authority's Urban Planning Department, working with a large survey related to the Finger Plan about the effects of the proximity to stations on office worker's travel behaviours. The Finger Plan work resulted in a large report on the topic. The joy of writing has furthermore resulted in two published fictional short stories.

In 2017, Ida once more adjusted her resource management and spatial planning focus to a new topic, this time turning her eyes to the seas by starting a PhD in Maritime Spatial Planning at Aalborg University Copenhagen as part of the BONUS BASMATI project.

English summary

Humans have used the seas since early human history but today, the interests in marine space amongst both traditional and new marine human uses are growing rapidly. This leads to increasing use-use conflicts and sometimes also to synergies due to spatial-temporal proximity. An increasing political and public awareness of the needs for managing marine human uses, while protecting marine ecosystems, has led to the emergence of marine spatial planning around the globe as a process to balance both marine use interests and environmental protection while including stakeholders and using best available data. The EU adapted the maritime spatial planning (MSP) Directive in 2014 which requires all coastal member states to have implemented one or more marine spatial plans for their marine territorial areas at 31st March 2021 the latest. The MSP Directive establishes ambitious minimum requirements to MSP but leaves it up to the member states how to weight individual objectives and how to accomplish them. One of these minimum requirements is the ambition to promote coexistence at sea but no clear co-location/coexistence definition exists. At the same time, an untapped potential exists for improving the inclusion of spatial decision support tools (DSTs) into MSP, as well as for improving functional abilities of such tools. Therefore, the objective of this PhD research is to provide an analytical co-location framework to clarify the meaning of the co-location concept and to design and develop a new spatial DST for facilitating co-location in MSP. The geographic focus is on the Baltic Sea region due to its transboundary MSP frontrunner position, but it is the intention that the findings could be adapted to other marine areas.

Three research questions guide this thesis with a chapter dedicated to each of them. The first research question concentrates on building the analytical co-location framework and using it to analyse the strengths and weaknesses of the way existing spatial DSTs target co-location. The second research question targets the co-location limitations of existing spatial DSTs through the design and development of a new spatial DST that simultaneously with its co-location focus aims at meeting general recommendations for spatial DSTs regarding functional abilities. The third research question explores the way in which the new spatial DST facilitates integrative, holistic MSP to meet the ambitious MSP minimum requirements.

Four papers contribute to the research questions. Paper 1 presents the analytical co-location framework to define co-location and its role in MSP and to present procedural steps to guide spatial DSTs towards facilitating co-location. The framework is applied to analyse existing spatial DSTs to reveal their co-location-related limitations. A new spatial DST called the SEANERGY approach is developed to target co-location and is implemented as three different tool versions with different purposes. The main SEANERGY version, presented in Paper 2 and Paper 3, is available as open source on GitHub. It is an ArcMap Python-based toolbox that enables a spatial, scenario-based approach to find multi-use potentials while minimising conflicts. It is stated to

be relevant for a wide span of MSP stakeholders. The main SEANERGY version synthesises conflict-synergy knowledge from the Baltic Sea to generate a proof-of-concept of SEANERGY consisting of pan-Baltic GIS analyses for conflicts and synergies between marine human uses. Paper 2 shows how SEANERGY supplement an environmental cumulative impact assessment (CIA) approach by enabling marine use coexistence where the cumulative impacts on the environment are low. The second SEANERGY version technically combines the two approaches by implementing SEANERGY methodology into the CIA-based MYTILUS platform, thereby supporting an ecosystem-based approach to MSP. The third SEANERGY version was designed to test the application of the SEANERGY approach in situ in a stakeholder workshop for local planners surrounding a Danish offshore wind farm case in a smaller marine area. The workshop was hosted by the SEAPLANSPACE project and took place summer 2020. The SEAPLANSPACE workshop findings are not peer-reviewed but suggest important strengths of the SEANERGY approach in its ability to visualise spatial conflict-synergy patterns and initiate discussions among stakeholders in MSP regarding synergies and trade-offs based on iteratively changing input scores. The findings from Paper 3 reveals that the SEANERGY approach contributes to all integrative dimensions of MSP spanning knowledge, data, sector, policy, stakeholder, transboundary, multi-scale, and land-sea integrative dimensions but simultaneously depends on integrative MSP including harmonised data.

The co-location framework and the SEANERGY approach present MSP planners, spatial DST developers, and sector representatives with options to gain a better understanding of the co-location concept, explore conflict-synergy maps and statistics, and facilitate scenario-driven stakeholder discussions based on iterative changes to input scores. The findings enable MSP to better increase multi-use at sea, minimise/avoid conflicts, optimise the use of marine space, while considering the health of ecosystems. Those are tasks that will only become increasingly important for MSP, as the use-use interactions at sea continue to intensify.

Dansk resume

Mennesker har benyttet sig af adgangen til havet siden menneskets tidlige historie, men i dag vokser interessen for pladsen på havene sig med hastig fart både blandt traditionelle og nye menneskelige havaktiviteter. Det fører til stigende konflikter og undertiden også til synergier mellem forskellige havaktiviteter på grund af tæt placering i tid og rum. En stigende politisk og offentlig bevidsthed om behovet for at håndtere menneskelige havaktiviteter og samtidig beskytte marine økosystemer har ført til den globale fremkomst af havplanlægning som en proces til at balancere brugsinteresser med miljøbeskyttelse på havet, inkludere interessenter i processen og anvende de bedste tilgængelige data. EU indførte det europæiske havplanlægningsdirektiv i 2014, hvilket stiller krav om, at alle kystnære EU-medlemslande skal have implementeret en eller flere havplaner for deres nationale havterritorier senest den 31. marts 2021. Havplanlægningsdirektivet rummer ambitiøse minimumskrav til MSP, men lader det være op til medlemsstaterne, hvordan de enkelte målsætninger skal vægtes, og hvordan de kan opnås. Et af disse minimumskrav er ambitionen om at fremme sameksistens til søs, men der findes ingen klar definition af samlokalisering/sameksistens-begrebet. Der eksisterer samtidig et uudnyttet potentiale til at forbedre inddragelsen af rumlige beslutningsstøtteværktøjer i havplanlægningsprocessen samt til at forbedre sådanne værktøjers funktionelle egenskaber. Derfor er formålet med dette ph.d.-projekt at bidrage med en analytisk ramme for begrebet samlokalisering for at tydeliggøre begrebets betydning og at designe og udvikle et ny rumligt beslutningsværktøj til at facilitere samlokalisering i havplanlægningsprocessen. Det geografiske fokus er på Østersøregionen på grund af dens frontløberposition i forhold til havplanlægning på tværs af landegrænser, men det er intentionen, at resultaterne kan tilpasses andre havområder.

Tre forskningsspørgsmål guider denne afhandling med et kapitel dedikeret til hvert. Det første forskningsspørgsmål koncentrerer sig om at opbygge den analytiske samlokaliseringsramme og bruge den til at analysere styrker og svagheder ved den måde, hvorpå eksisterende rumlige beslutningsværktøjer håndterer samlokalisering. Det andet forskningsspørgsmål håndterer samlokaliseringsrelaterede mangler ved rumlige beslutningsværktøjer ved at designe og udvikle et nyt rumligt beslutningsværktøj, der samtidig med sit fokus på samlokalisering har til hensigt at opfylde generelle anbefalinger til rumlige beslutningsværktøjer vedrørende funktionelle evner. Det tredje forskningsspørgsmål undersøger på hvilke måder, at det nye rumlige beslutningsværktøj faciliterer integrerende, holistisk havplanlægning, der skal opfylde de ambitiøse minimumskrav til havplanlægningsprocessen.

Fire artikler bidrager til forskningsspørgsmålene. Artikel 1 præsenterer den analytiske samlokaliseringsramme med henblik på at definere samlokalisering og dets rolle i havplanlægningsprocessen og for at præsentere en trinbaseret vejledning til rumlige beslutningsværktøjer for, hvordan de kan facilitere samlokalisering. Rammen

anvendes til at analysere eksisterende rumlige beslutningsværktøjer for at fremhæve deres samlokaliserings-relaterede begrænsninger. Et nyt rumligt beslutningsværktøj med titlen SEANERGY er udviklet med fokus på samlokalisering og implementeres som tre forskellige værktøjsversioner med forskellige formål. Den vigtigste SEANERGY-version præsenteres i artikel 2 og i artikel 3 og er tilgængelig som open source på GitHub. Det er en ArcMap Python-baseret værktøjskasse, der muliggør en rumlig, scenariebaseret tilgang til at finde potentialer for flersidet brug af havet samtidig med, at konflikter minimeres. Der argumenteres for dens relevans for en bred vifte af havplanlægningsinteressenter. Hovedversionen af SEANERGY samler konflikt-synergi-viden fra Østersøen med henblik på at demonstrere analysemulighederne i SEANERGY gennem panbaltiske GIS-analyser for konflikter og synergier mellem havaktiviteter. Artikel 2 viser, hvordan SEANERGY med fordel kan supplere en kumulativ konsekvensanalysetilgang til påvirkninger på miljøet ved at muliggøre sameksistens til havbrug, hvor de kumulerede påvirkninger af miljøet er små. Version to af SEANERGY kombinerer på teknisk vis de to tilgange og understøtter derved en økosystembaseret tilgang til havplanlægningsprocessen ved at implementere SEANERGY-metoden i MYTILUS, som er et værktøj, der har fokus på kumulerede påvirkninger af miljøet. Version tre af SEANERGY blev designet til at teste anvendelsen af SEANERGY-tilgangen *in situ* i en interessentworkshop for lokale planlæggere, der havde fokus på en dansk havvindmøllecase i et mindre havområde. Workshoppen blev arrangeret af SEAPLANSPACE-projektet og fandt sted i sommeren 2020. Resultaterne fra SEAPLANSPACE-workshoppen er ikke blevet underlagt en akademisk uafhængig bedømmelse, men indikerer vigtige fordele ved SEANERGY-tilgangen i dens evne til at påpege rumlige konfliktsynergimønstre og indlede diskussioner blandt interessenter i havplanlægningsprocessen om synergier og kompromiser ud fra iterativt at ændre inputscorer. Resultaterne fra artikel 3 afslører, at SEANERGY-metoden bidrager til alle integrerende dimensioner af MSP, der spænder over viden, data, sektorielle interesser, politiske interesser, interessentinddragelse, tværnationale samarbejder, multi-skala og land-hav-integrerende dimensioner, men at SEANERGY-metoden samtidig afhænger af integreret havplanlægning f.eks. harmoniserede data.

Samlokaliseringsrammen og SEANERGY-tilgangen præsenterer havplanlæggere, udviklere af rumlige beslutningsværktøjer og sektorrepræsentanter med muligheder for at få en bedre forståelse af samlokaliseringsbegrebet, udforske konfliktsynergikort og -statistikker og facilitere scenariedrevne interessentdiskussioner baseret på iterative ændringer af inputscorer. Resultaterne støtter havplanlægning i at skærpe flersidigt brug af havet, minimere/undgå konflikter og optimere pladsanvendelsen på havet, samtidigt med, at der tages højde for økosystemers tilstande. Det er opgaver, der kun bliver endnu vigtigere for havplanlægningsprocessen, i takt med at interaktioner mellem menneskelige aktiviteter på havet yderligere intensiveres.

Preface

“I really don't know why it is that ***all of us*** *are so* ***committed to the sea****, except I think it is because in addition to the fact that* ***the sea changes*** *and* ***the light changes****, and* ***ships change****, it is because* ***we all came from the sea****.*”

These famous words were spoken by the president of the USA, John F. Kennedy, himself a sailor, at a dinner for the America’s Cup Crews 14^{th} September in 1962. The words imply many remarkable aspects of the sea. The fascination held by humans towards the sea. It’s recreational and poetic inspiration. The various moods evoked by the sea. A water surface with different lightings, colours, and tempers. It’s beauty, it’s rage. Its mysterious and deep unknowns at its largest depths. It’s rapid changes and dynamical flows. The fact that humans evolve, and ships change, but we humans keep on sailing and using the oceans. The fact that life began in the oceans, and the fact that we still depend on the marine ecosystems.

Fiftyfive years and one day after Kennedy’s famous quote, I started my PhD in maritime spatial planning (MSP). With this topic, I was thrown into deep, since I had only been occupied with terrestrial, urban planning until then. During my PhD I have had the pleasure of working with a spatial planning field that is much newer from a legal perspective than terrestrial planning, since the MSP Directive entered into force as late as 2014. However, humans have actively and indirectly used the oceans since the beginning of civilisation. Today, with the rapid population growth causing an increasing activity level at sea, an increasing pollution level from land, and with climate change effects escalating, we humans need to pay attention to what happens in the sea, now more than ever. We need to acknowledge the importance of ecosystem services for human health of which many originate in the sea and the coastal areas. More than two thirds of the Earth’s surface are covered by water, and yet, we call it planet Earth. We humans tend to often take an anthropocentric attitude towards our surroundings. However, we also realise – though often not to a high enough degree – how much we depend on these natural surroundings, on the ecosystem services they provide us with, and the oceans themselves. Land and sea are connected. We are (or at least we need to be) committed to the sea.

Information on funding

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Acknowledgements

This PhD journey has at times been “salty” – like the marine environment it studies – involving (symbolic) blood and sweat. However, it has to a larger degree been refreshing and inspiring – such as the marine environment can also be. I am extremely grateful for all the academic and personal support I have been provided during this journey of academic and personal learning and performance.

It has been a tremendous inspiration and opportunity to be part of BONUS BASMATI, the larger Baltic Sea international MSP research project, keeping me inspired and on track. With a PhD project that studies a topic of pan-Baltic importance, it has been crucial to be part of a pan-Baltic collaboration myself. Thank you to all partners in the BONUS BASMATI project for your direct and indirect inspiration. I have enjoyed drawing on your different international backgrounds and varied and cross-disciplinary experience. Thank you in particularly to Harri and Hanna, for welcoming me to a two months stay at Turku University in Finland, introducing me to local marine conflict and synergy examples and to Finnish culture, and enable me to share and discuss my research at a Finnish geographic university department. Thank you to Christian, Pyry, and Juha at the Finnish Geodetic Research Institute for all your insights on spatial decision support tools and for always being ready to help with Baltic Explorer. Thank you to the Nordregio team for your insights, particularly on stakeholder involvement, and your always interesting questions to my PhD, and for interesting coffee talks, Andrea. To Pia, thank you for a very interesting, fruitful, and fun collaboration on the SEAPLANSPACE workshop and for your clever insights on sustainability in MSP. In addition, to my two fellow PhD students at BONUS BASMATI, Miriam and Aurelija, as well as to Trine at AAU: it has been a pleasure to be on this journey together with our parallel topics supporting each other well.

I would not have been provided this PhD opportunity, had it not been for my main supervisor, Henning, and your dedication to boosting my academic career. Thank you to you as well as to my co-supervisor Lise. You have both dedicated a tremendous amount of time to supervising this PhD project. You have always been ready 24/7 with support, encouragement, sharing of your life experiences, and good collegial talks.

Lastly, many thanks to my family. To my parents, Anne-Mette and Bent, thank you for encouraging me to pursue this path and always be there for me. To my sister Ane, thank you for listening and asking curious GIS questions. To my lovely son, Elias, thank you for reminding me that time is valuable. To my husband, Rasmus, thank you for your love as well as your clever insights. You have provided tremendous personal support, inspiring conversations, mathematical formula experience, thesis proofreading, and have in general enabled me to dedicate my time to this project.

Abbreviations

CIA: Cumulative Impacts Assessment

CSA: Culturally Significant Area

DST: Decision Support Tool [spatial DSTs is the focus in this thesis]

EC: European Commission

EU: European Union

EUSBR: European Union Strategy for the Baltic Sea Region

GIS: Geographic Information System

HELCOM: the Baltic Marine Environment Protection Commission, also called the Helsinki Commission

HELCOM-VASAB: an MSP Working Group where HELCOM and VASAB join forces

ICZM: Integrated Coastal Zone Management

IMP: Integrated Maritime Policy

MPA: Marine Protected Area

MMR: Minimum MSP requirement

MSFD: Marine Strategy Framework Directive

MSP: Maritime Spatial Planning [in a global context: Marine Spatial Planning]

R: Recommendation [used to list general recommendations to spatial DSTs]

RQ: Research question

VASAB: Vision and Strategies around the Baltic Sea

UNCLOS: United Nations Convention on the Law of the Sea

Papers

PhD papers

- **Paper 1**: Bonnevie, I.M., Hansen, H.S. & Schröder, L. (2019). Assessing use-use interactions at sea: a theoretical framework for spatial decision support tools facilitating co-location in maritime spatial planning. *Marine Policy*, 106, 103533, https://doi.org/10.1016/j.marpol.2019.103533
- **Paper 2**: Bonnevie, I.M., Hansen H.S., Schrøder L. (2020a). SEANERGY – a spatial tool to facilitate the increase of synergies and to minimise conflicts between human uses at sea. *Environmental Modelling and Software*, 132, 104808, https://doi.org/10.1016/j.envsoft.2020.104808
- **Paper 3**: Bonnevie, I.M., Hansen, H.S. & Schrøder, L. (2020b) Supporting integrative maritime spatial planning by operationalising SEANERGY – a tool to study cross-sectoral synergies and conflicts. *International Journal of Digital Earth*, https://doi.org/10.1080/17538947.2020.1865467
- **Paper 4**: Hansen, H.S. & Bonnevie, I.M. (2020). A toolset to estimate the effects of human activities in maritime spatial planning. In: ICCSA 2020: 20th International Conference, Cagliari, Italy, July 1-4 2020. *Proceedings, Part IV, Lecture Notes in Computer Science (LNCS)*, 12252. Springer, Switzerland, pp. 521-534, https://doi.org/10.1007/978-3-030-58811-3_38

Other PhD-related publications

- *Popular article*: Bonnevie, I.M. (2020). Can we diminish conflicts at Sea? [title translated from Danish]. In: Geoforum Denmark (eds.), *Geoforum: Theme: Work of the Young People [title translated from Danish]*, Geoforum membership magazine for Danish land surveyors, No. 215, June 2020.
- *Being co-author of*: Arki, V., Ajanko, J., Luhtala, H. & Tolvanen, H. (eds.) (2020) *BONUS BASMATI – Supporting maritime spatial planning with science*. BONUS BASMATI Deliverable 7.7, September 2020, www.bonusbasmati.eu
- *Interviewed for inputs to*: Eliasen, S.Q., Cedergren, E., Morf, A, & Gee, K. (2020). *Lessons learned – Knowledge integration tools for MSP by BONUS BASMATI*. BONUS BASMATI Deliverable 2.4, September 2020, www.bonusbasmati.eu

Presentations

Conferences

- Bonnevie, I.M., Hansen, H.S., Schrøder, L. (2019, June): *Spatial analysis of co-location in MSP* (30 minutes, keynote presentation) at the Final conference for the Plan4Blue project in Helsinki, Finland, in session *Spatial analysis of socioeconomic-environmental interactions* with session chair: Tolvanen, H..
- Bonnevie, I.M., Hansen, H.S., Schrøder, L. (2019, June): *Assessing synergies and conflicts arriving from spatial-temporal proximity between marine human-based uses* (12 minutes) at the Future Oceans2 IMBeR Open Science Conference in Brest, France, in session *Marine governance, challenges for sustainability* with conveners: Glaser, M., Zivian, A., Gerhardinger, L., Newton, A.
- Bonnevie, I.M., Hansen, H.S., Schrøder, L. (2019, August): *Assessing synergies and conflicts between marine human activities in close spatial-temporal proximity* (15 minutes) at the Baltic Sea Science Congress in Stockholm, Sweden, in *Session 2: Coastal Seascapes and Dynamics* with session chair: Eklöf, J.
- Bonnevie, I.M., Hansen, H.S., Schrøder, L. (2019, September): *Managing conflicts and synergies of use-use interactions* (10 minutes) at the ICES Annual Science Conference 2019 (ICESASC19) in Gothenburg, Sweden in the session *Theme session F: Management objectives, trade-offs and strategies in a changing ocean* with conveners Tan, J., Kerr, L., Thorpe, R.
- Hansen, H.S., Bonnevie, I.M., (2020, July): *A Toolset to Estimate the Effects of Human Activities in Maritime Spatial Planning* (8 minutes) at the 20th International Conference on Computational Science and its Applications, online, in session *GEOG-AND-MOD-1* with convener: Murgante, B.

Other presentations

- Bonnevie, I.M., Hansen, H.S. (2018, August). Part of exhibition *Lab5: Marine charts: Focusing on charts and geographic infrastructure for the marine territory* [title translated from Danish] (1 day workshop with land surveyors and 1 day workshop with the public) at The 250 years anniversary of the surveying profession at Aalborg University, Aalborg, Denmark.
- Bonnevie, I.M., Hansen, H.S., Schrøder, L. (2018, October): 11 months PhD seminar presentation *Developing a ranking-based GIS approach to co-locate marine human activities* (45 minutes) at the BONUS BASMATI 3rd Partner

meeting at Finnish Geodetic Institute, Helsinki, Finland. Opponent: Tolvanen, H., University of Turku, Finland.

- Bonnevie, I.M. (2019, January): *Co-location in maritime spatial planning in the Baltic Sea* (45 minutes) at the *Thursday lunch seminar* at the Department of Geography, University of Turku, Finland.
- Bonnevie, I.M., Hansen, H.S., Schrøder, L. (2019, January): *Co-location in the Baltic Explorer* (5 minutes) at BONUS BASMATI WP5 partner meeting at Finnish Geodetic Institute FGI, Helsinki, Finland.
- Bonnevie, I.M., Hansen, H.S., Schrøder, L. (2019, September): *Developing a ranking-based GIS approach to co-locate marine human activities* (10 minutes) at the BONUS BASMATI 5th Partner meeting at Aalborg University Copenhagen, Denmark.
- Bonnevie, I.M., Frederiksen, P. (equal workload) (2020, August): Monday 17. August 2020: *Marine scenarios: Conflicts and synergies between marine uses* [title translated from Danish] (10 minutes presentation followed by a 2 hour long workshop) at the SEAPLANSPACE workshop No. 7: on *coastal and ocean-based cultural heritage in the Baltic Sea: tourism, recreation, and sustainability challenges* at Aalborg University Copenhagen, Denmark. Convenors: Frederiksen, P., Schrøder, L, Bonnevie, I.M.

Software availability

SEANERGY

- Developer: Ida Maria Bonnevie
- E-mail: idarei@plan.aau.dk
- Available here: https://github.com/IdaMBonnevie/SEANERGY.git
- Year first available: 2020
- Program specifications: SEANERGY is an ArcMap-based toolbox with six tools developed in Python for spatially locating potential synergies and conflicts between marine uses based on a pairwise comparison matrix.
- Metadata: Tool and data descriptions are described in a metadata file available in the tool package. Interactive metadata is built into the individual tools. The tool package comes with preprocessed proof-of-concept Baltic Sea data but can be adjusted to work for other marine areas.
- A preprocessing tool is available here: https://github.com/IdaMBonnevie/SEANERGY-preprocessing.git
- Software and license dependencies: The full program depends on a Windows 10 system with ESRI ArcMap installed including the ArcMap extension Spatial Analyst and including the Python modules arcpy, os, pandas, numpy, collections, time, datetime. The program has been developed for the versions ArcMap 10.7 and Python 2.7. The toolbox interface requires an ESRI ArcMap license and the Spatial Analyst ArcMap-extension. However, the Python code is open source and the methodology can thus freely be implemented into own programs with credits to the author of the approach.
- Program size: 4.07 MB.

MYTILUS – available with parts of the SEANERGY approach

- Developer: Henning Sten Hansen
- E-mail: hsh@plan.aau.dk
- Availability: It can be acquired by contacting its developer.
- Program introduction: MYTILUS is an open source, free, and fast desktop-based spatial decision support tool to calculate cumulative impacts assessments (CIA) on the environment. It is based on the fast Delphi 10.1 Integrated Development Environment from Embarcadero5 (Hansen 2019).

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Chapter 1.
Introduction and scope

With human uses increasing their intensity and expanding their presence at sea, it is an increasingly needed, and increasingly challenging task, to manage marine areas. The European Union (EU) has implemented a relatively new directive on maritime spatial planning (MSP), aiming to promote coexistence amongst activities at sea. As this chapter will outline, co-location between marine uses at sea is a topic that needs further research.

1.1. Introduction

Over the last century scientific knowledge, drawing on many different scientific fields, has revealed deep links between the human world and the natural world. A significant part of the natural world is blue and marine. Among us humans, our increasing pressures on marine ecosystems have initiated public, political, and scientific awareness over the links between our world and the marine world (Cheung et al. 2019). The marine world has long been a centre for attention by many different scientific disciplines such as philosophy, geography, military studies, navigation and seafaring, natural sciences, political sciences, social sciences. These have inspired art, literature, and music. Recently, the time has come for planning to give the seas attention too (Gee 2019). Throughout history, people have used the marine world for traditional purposes such as transportation and fishing but with today's rapidly increasing human use of ocean space, we humans need to manage ocean space as never before (Hammar et al. 2020).

1.1.1. Increased competition at sea

Competition between marine human uses is growing at a global scale (Schupp et al. 2019). Many marine human activities are expanding their use of marine space, while relatively new marine uses, for example, renewable energy, scientific research, and aquaculture compete for marine space internally among each other and with more traditional marine uses, for example, cruise shipping, tourism, fishing, oil and gas, and military (Klinger et al. 2018; Kannen 2014). The trend towards increased competition is promoted within the EU through its Blue Growth Strategy (EC 2012). The EU Blue Growth Strategy for Opportunities for Marine and Maritime Sustainable Growth highlights some marine sectors with particular potentials for growth: renewable offshore energy, aquaculture, marine/coastal and cruise tourism, mining of marine mineral resources, and marine biotechnology (Klinger et al. 2018; EC 2012).

The growing competition and activity level at sea increases the pressures on ecosystems and highlights the need for effective, integrative spatial planning of marine uses (Coccoli et al. 2018; Stuiver et al. 2016). The dynamics of the seas are faster and more movement-based than on land, since water, as per definition, is fluid, causing many marine resources and many marine uses to be in continuous movement (Jay et al. 2016). Furthermore, marine areas often need to be considered in 4D, distinguishing between benthic areas, the water column, and the water surface, and over time, whereas the depth dimension and temporal dimension are typically less urgent for planning on land (Papageorgiou & Kyvelou 2018; Depellegrin et al. 2017). To solve conflicts between marine uses (*use-use conflicts*) and conflicts between marine uses and the environment (*use-environment conflicts*), MSP has gained attention across the world as a tool to spatially plan the oceans (Santos et al. 2020; Kull et al. 2019).

1.1.2. A UNESCO guide to MSP

A UNESCO guide for how to do MSP by Ehler & Douvere (2009) defines marine spatial planning (MSP) in the following way:

"Marine spatial planning (MSP) is a public process of analysing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that are usually specified through a political process."

Based largely on MSP experiences from around the world, the UNESCO guide suggests 10 steps with various sub-steps for how to do MSP. An adaptation of the stepwise guide is illustrated in Figure 1. At an overall level, the guide by Ehler & Douvere (2009) involves planning, implementing, monitoring, and evaluating, before iteratively adapting to a new planning phase bringing new knowledge along. At a more specific level, it involves 10 steps where the planning phase includes the most steps. These 10 steps again include sub-steps. The sub-steps are coloured in Figure 1 to reflect how MSP is both a practical process, a political/objectives-based process, a stakeholder-based process, and a data-driven process, the latter reflected in the fact that step 5, 6, 7, and 9 explicitly include the words *"mapping"*, *"zoning"* and/or *"modelling"* (Ehler & Douvere 2009).

1.1.3. MSP in the EU

In the EU, MSP has gained attention as a tool to make use of economic marine opportunities and balance cross-sectoral marine interests, while acknowledging the importance of and need for protecting ecosystem services (Friess & Grémaud-Colombier 2019; Kannen 2014). MSP was implemented into EU legislation with the

MSP Directive from 2014, which demands all the coastal EU countries to implement one or more marine spatial plans for their marine areas with the 31st of March 2021 as deadline for implementation (EC 2014).

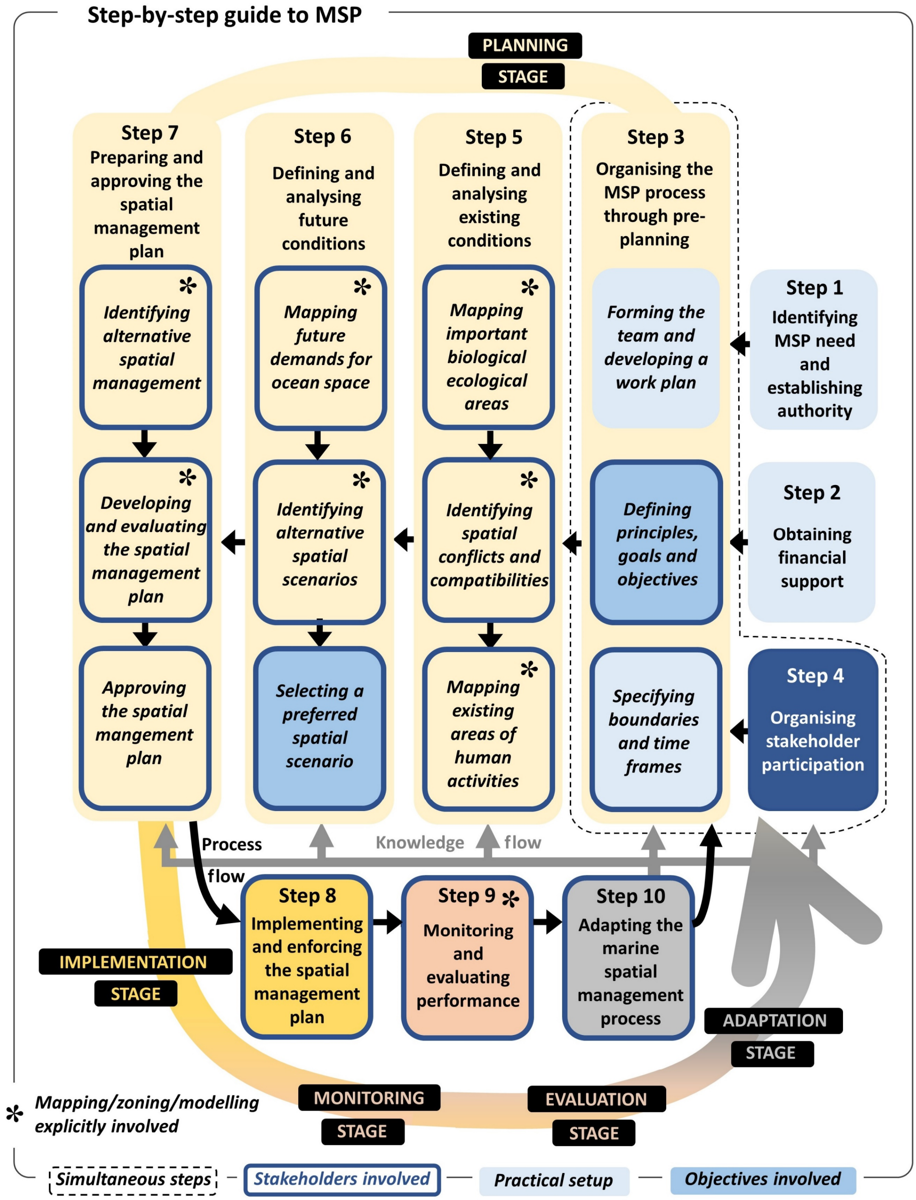

Figure 1: A stepwise model to do MSP. Adapted from Ehler & Douvere (2009).

1.1.3.1. The MSP Directive as a supplement to other policies

The MSP Directive supplements and refers directly to The United Nations Convention on the Law of the Sea of 1982 (UNCLOS) which is a more globally spanning regulation defining the rights and responsibilities regarding the use by nations of seas and oceans. UNCLOS defines the territorial waters of each country to be up to 12 nautical miles from the coastline where the corresponding country has full jurisdiction. Besides the territorial water, a country can claim an exclusive economic zone (EEZ) up to 200 nautical miles from the coastline in which that country is provided the rights to explore, exploit, and conserve natural resources without hindering other countries' navigation and cable interests in that area (UNCLOS 1982). For overlapping EEZ claims, the involved countries need to come to an agreement about where the border is drawn based on an equality principle (UNCLOS 1982).

Furthermore, the MSP Directive supplements and refers directly to other EU policies than itself including the EU's Blue Growth Strategy (EC 2012), the Integrated Maritime Policy (IMP) for sustainable development at seas (EC 2007), the Marine Strategy Framework Directive (MSFD) from 2008 for preserving and achieving good environmental status of oceans (EC 2008), and Integrated Coastal Zone Management (ICZM) (EC 2002). As Santo (2011) points out, other important EU strategies to put MSP on the EU agenda include the Habitats Directive from 1992 (92/43/EEC), the Common Fisheries Policy from 2002, and the Water Framework Directive (2000/60/EC). The ambition for the MSP Directive to bridge between all these many and different policies is expressed through a wide span of objectives reflected in its minimum MSP requirements.

1.1.3.2. Minimum MSP requirements and a high degree of flexibility

The MSP Directive establishes some minimum requirements (MMRs) for the coastal EU member states to implement maritime spatial plans for their marine waters which must be implemented by March 31st 2021 at the latest (EC 2014). The MMRs are stated in Article 6, which draws explicit links to Article 5, 9, 10, 11, and 12 (EC 2014). The MMRs are neither ranked nor listed with numbers in the MSP Directive but are indexed here with the sole purpose of structuring them into themes.

Whilst all MMRs are important for both the process, data, and results of MSP, some of them appear to be more oriented towards the results. Regarding these more result-oriented goals of the maritime spatial plans, important MMRs are for the member states to *"support sustainable development and growth in the maritime sector"* (MMR1 in Article 5), base the plans on *"an ecosystem-based approach"* and contribute to *"the preservation, protection and improvement of the environment"* (MMR2 in Article 5), contribute to *"resilience to climate change impacts"* (MMR3 in Article 5), *"promote coexistence of relevant activities"* (MMR4 in Article 5), take into account *"environmental, economic and social aspects, as well as safety aspects"* (MMR5 in Article 6), and *"take into account land-sea interactions"* (MMR6 in Article 6), the latter to bridge the gap between terrestrial and marine spatial planning (Tsilimigkas & Rempis 2017).

Of the MMRs that appear to be more process- and data-oriented goals, important MMRs involve *"consulting the relevant stakeholders and authorities, and the public concerned, at an early stage in the development of maritime spatial plans"* (MMR7 in Article 9), *"organise the use of the best available data"* (MMR8 in Article 10), cross-border *"cooperation among member states"* and *"with third countries"* (MMR9 in Article 11 and Article 12), and requirements for an iterative process where the plans are updated *"at least every ten years"* (MMR10 in Article 6). The list of specific marine uses to include is a mix of mandatory sectors and explicitly suggested sectors. Since MSP, as per definition, makes up a cross-sectoral, holistic, integrative approach, no activities can be considered in isolation within MSP (Westholm 2018). Mandatory sectors to consider are energy, maritime transport, fisheries, aquaculture, as well as protection/improvement of the environment, of nature, and of species. Sustainable tourism, dredging, scientific research, and communication cables are directly mentioned in Article 5 as optional sectors to include, and this list is extended in Article 8 to also include military training areas, scientific research, and underwater cultural heritage (MMR11). While these minimum requirements exist, it is up to the member states themselves to determine *"how the different objectives are reflected and weighted"* (MMR12 in Article 5). The minimum MSP requirements (MMRs) are summed up in Figure 2.

MMR12 reflects how the MSP Directive allows a high degree of flexibility between the member states. The MSP Directive has been categorised as an example of a *"new generation directive"* being less precise regarding compliance requirements and providing member states with more freedom to interpret their objectives compared to earlier Directives (Hassler et al. 2019). The member states even decide themselves on their choice of governance structures for their maritime spatial plans (Article 4), their planning authorities (Article 13), and they keep their sovereignty (Article 2). Furthermore, they have the option to exclude coastal marine waters falling under town and country planning (Article 2), leaving the focus to be on the territorial waters and exclusive economic zones (EEZ) (Friess & Grémaud-Colombier 2019). Member states can differ to which degree they are more centralised versus decentralised in their MSP authority structures, for example, whether they divide their marine areas into more plans with different authorities or keep one national plan under one national authority. Such differences can increase transnational coordination costs (Hassler et al. 2019). The overall perspective can be lost in a decentralised regime, whereas details may be lost in a more centralised regime where typically only one national maritime spatial plan exists (Westholm 2018).

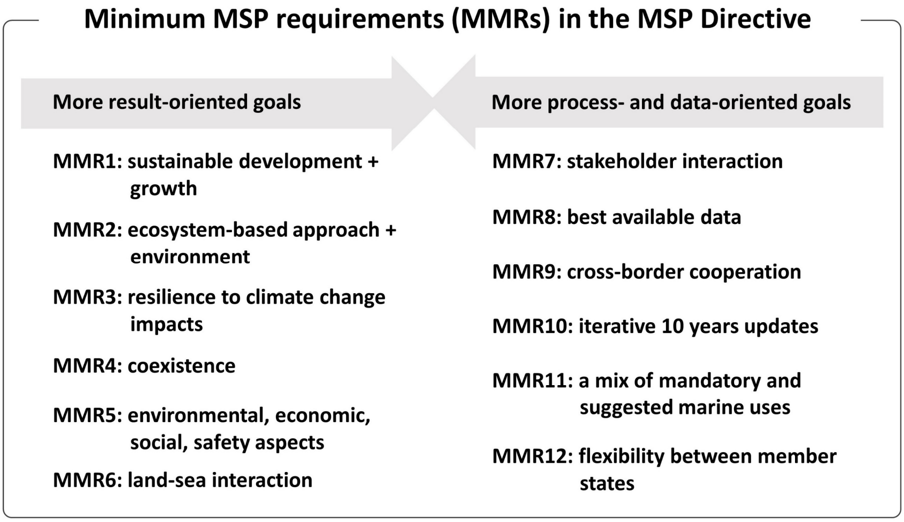

Figure 2. Minimum MSP requirements (MMRs). The MMRs are deduced from EC (2014). All MMRs influence MSP results as well as process/data, yet here they have been attempted categorised after their strongest appearing characteristic.

A constructive side to the flexibility to do MSP is that it allows for easier implementation into national planning context (Friess & Grémaud-Colombier 2019). However, the flexibility poses some challenges regarding achieving the ambition of stakeholder involvement, coherent sea basin strategies, and cross-border cooperation. For example, the MSP Directive does not contain many details on how to include stakeholders, leaving it up to each country to decide who to include, whether to actively engage them (formative inclusion) or only inform them (symbolic inclusion), how to carry out the planning process, and when in the planning process to include them (Hassler et al. 2019).

In addition, the flexibility for the member states to weight their goals and objectives enables the discussion of how to balance economic blue growth concerns and environmental concerns, the two pillars of MSP (Hassler et al. 2019; Gimpel et al. 2018; Rempis et al. 2018). By using the term maritime spatial planning instead of marine spatial planning, some researchers argue that the European Commission (EC) stresses the economic dimension more than the conservation-related aspect of MSP (Soma et al. 2015; Santo 2011). However, MSP does nevertheless demand an ecosystem-based approach as defined in the MSFD, thus requiring all member states to consider sustainability and the health of ecosystems besides blue growth (Soma et al. 2015; EC 2014).

1.1.3.3. An ecosystem-based approach to MSP

The MSFD implementation in 2008 marked an important step forward in the EU marine environmental policy with the direct aim to protect and preserve the marine environment to ensure a good environmental status of the ecosystems within the European marine regions (EC 2008). The EU contains eight marine regions/whole sea basins, including for example the Baltic Sea marine region (EC 2008 Article 4). The MSP Directive adopts this concept of marine regions from the MSFD as part of its ambition to ensure an ecosystem-based approach (EC 2014 Article 3). Such a focus on larger marine regions enables the EU to better consider the interconnectedness of natural resources and ecosystems across country boundaries (Friess & Grémaud-Colombier 2019).

However, no single internationally agreed-upon ecosystem-based approach exists, and MSP planners in the EU differ in their understandings of the concept. In fact, over the last decade of academic literature, twenty concepts have been found to overlap with the concept of an ecosystem-based approach with varying definitions, and many concepts being used without any definition at all (Kirkfeldt 2019). Despite the confusing landscape of ecosystem concepts, they all, as per definition, build on the concept of ecosystems.

Ecosystems consist of natural functions and processes that support species and provide ecosystem services to fulfil human life and thus benefit human uses (Liquete et al. 2013). The dynamics of ecosystems are difficult to fully comprehend and measure which is not made easier by the complexity added by climate change dynamics (Hansen 2019). The cascade model is a widely used model for conceptualising the ways in which marine uses benefit from having a good quality of life through ecosystem services (von Thenen et al. 2020). The specific definitions of cascade model elements vary between literature sources, but all versions of the cascade model seem to connect the nature-based system with the socio-economic system to describe how human wellbeing depends on the ability of underlying ecosystem dynamics to provide ecosystem services that humans give value to (von Thenen et al. 2020). In the nature-based end of the cascade model, biophysical structures and processes provide functions, constituting the ecosystem capacity. The functions provide provisioning ecosystem services, maintaining and regulating ecosystem services, and cultural ecosystem services in the form of service flows to humans that link the nature-based system with the socio-economic system. In the socio-economic end of the cascade, humans receive benefits from the ecosystem services that humans attach values to (von Thenen et al. 2020; Liquete et al. 2013).

Marine uses also put pressures on the environment and thereby (mostly negatively) impact the ecosystem services they benefit from, or even depend on (Klinger et al. 2018). Another conceptual model often used to depict how marine uses not only benefit from but also impact ecosystems is the DPSIR framework (Kelble et al. 2013;

Müller & Burkhard 2012; Atkins et al. 2011). Elliot et al. (2017) present a more advanced version of it called the DAPSI(W)R(M) framework (pronounced dap-see-worm). It links Drivers, Activities, Pressures, State changes, Impacts on Welfare and Responses as Measures. The DAPSI(W)R(M) describes how human basic needs, for example, for food, for water, for shelter, and more advanced needs, for example, for transport, for culture are drivers that drive human activities to make use of ecosystem services. The human activities lead to pressures which impact the ecosystems through state changes which impact their ability to produce ecosystem services which impacts human welfare. Human responses such as governance measures, for example, taxation, prohibition, or conservation zones can be introduced to influence the change in welfare through changes to human needs, to human activities, or to the pressures, initiating a new DAPSI(W)R(M) cycle (Elliot et al. 2017).

An ecosystem-based approach is in general understood to encompass the sustainable management of human activities so that humans do not destroy important ecosystem components (Westholm 2018). While MSP does not require neither the use of the cascade model nor the use of the DAPSI(W)R(M) framework, the combined model in Figure 3 visualises how planning for human uses need to consider an ecosystem-based approach due to the close dependency-and-consequence link between the nature-based system and the socio-economic system. The combined model is inspired by Frederiksen et al. (n.d.), the presentation of DPSIR in Elliot et al. (2017), and the ecosystem service cascade as presented in von Thenen et al. (2020) and Liquete et al. (2013).

To assist with an ecosystem-based MSP approach, the EU works ongoingly on providing guidelines to detect best available practices through for example the online msp-platform.eu and providing funds for sea basin collaboration projects (Friess & Grémaud-Colombier 2019). One European marine region that has participated in many sea basin collaboration projects is the Baltic Sea region.

1.1.3.4. The Baltic Sea region as frontrunner

The Baltic Sea region has experienced almost two decades of EU-financed coastal and marine planning projects, and some projects are still ongoing. In fact, the Baltic Sea region is a frontrunner, when it comes to cross-border, transboundary, sea basin collaboration projects (Moodie et al. 2019).

The Baltic Sea countries clearly reflect the large flexibility of how to do MSP within the EU (Hassler et al. 2019). In the Baltic countries with a Baltic Sea coastline, it varies from country to country, whether it is a Ministry of Finance or a Ministry of Environment that oversees the MSP process. The choice reflects whether one can expect the specific country to have a higher economic focus than environmental, or the other way around. In Denmark, Poland, Germany, and Estonia, the authorities responsible for MSP have a more economic focus, while Sweden, Finland, Lithuania and Latvia have put environmental authorities in charge of MSP (Westholm 2018). Thus, the institutional planning settings of member states reflect and affect their planning rationales. Neighbouring countries *"can diverge substantially in how the ecological, economic, and social dimensions of sustainability are balanced"* (Hassler et al. 2019). Furthermore, the Baltic Sea countries differ with regards to how far they are in the MSP process, how many marine spatial plans they produce for their marine areas, as well as at what vertical institutional level their MSP process is carried out. For example: Denmark, Poland, Estonia, and Lithuania implement MSP at a more national, top-down level; Germany combines a national and regional level for MSP with multiple marine spatial plans; Sweden and Latvia combine a national and local level for MSP, Sweden with multiple marine spatial plans; and Finland combines a regional and local MSP level with multiple marine spatial plans (Westholm 2018). Besides these eight Northern European countries, the Baltic Sea region includes the non-EU-member-country Russia where the MSP Directive does not apply. The coastal areas of all nine countries together with the Baltic Sea and its bathymetry profile are visualised on the map in Figure 4.

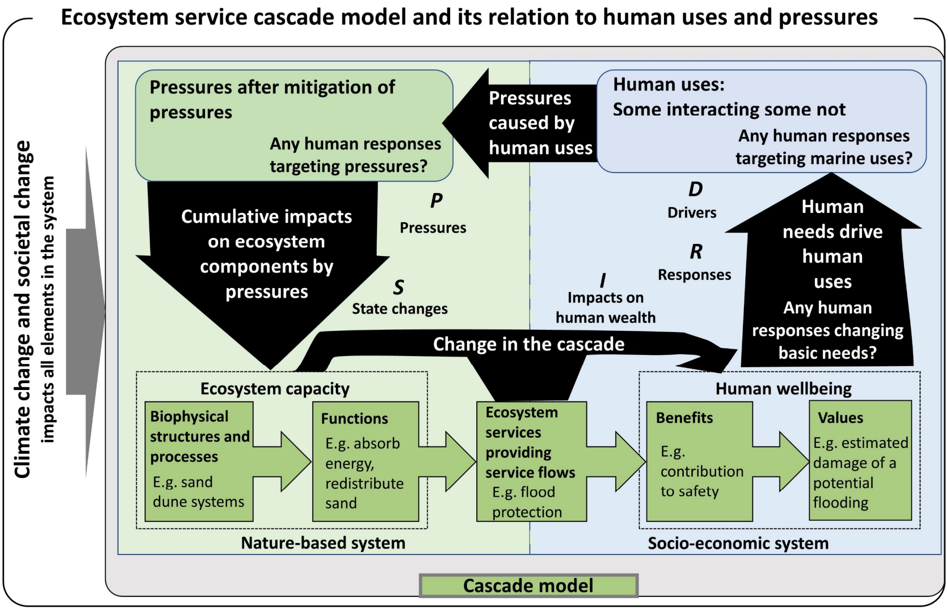

Figure 3. Model that links the nature-based system and the socio-economic system. The black arrows represent DPSIR-driven change to the ecosystem service cascade. This figure is inspired from Frederiksen et al. (n.d.), von Thenen et al. (2020), and Liquete et al. (2013).

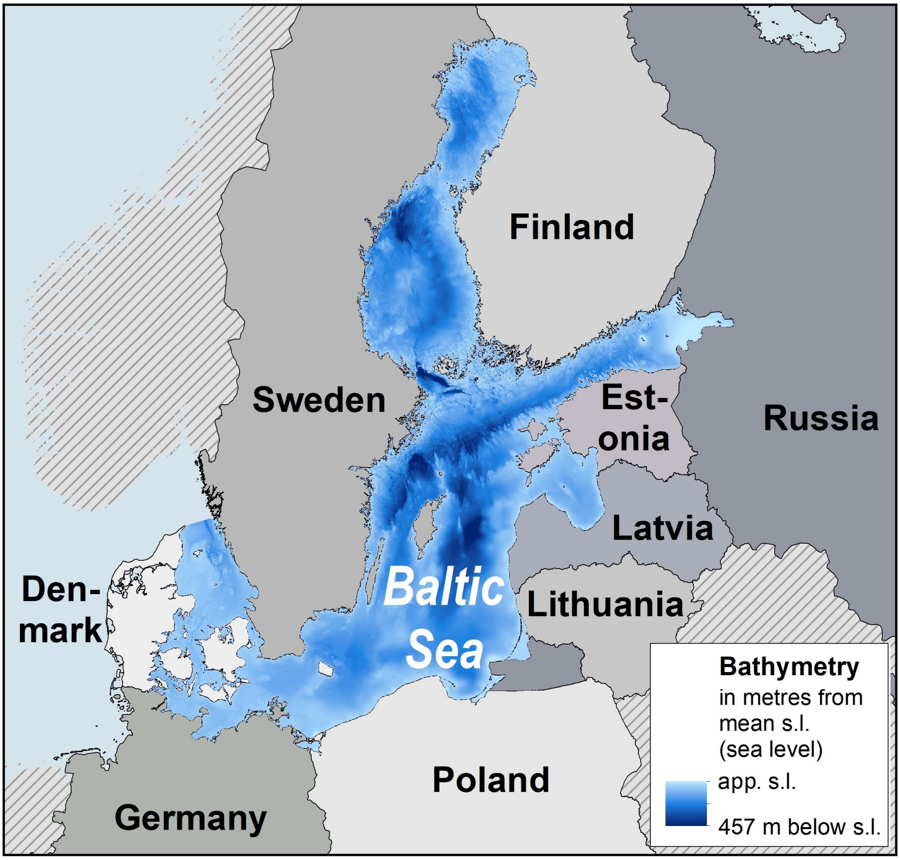

Figure 4. The Baltic Sea region. HELCOM's Baltic Sea bathymetry profile and the coastal profile of all nine Baltic Sea countries. Reprint from Bonnevie et al. (2020a).

MSP in the Baltic Sea region is guided by what started as two separate regional intergovernmental organisations in the early 2000s: the EU regional sea convention for the Baltic Sea called the Baltic Marine Environment Protection Commission or the Helsinki Commission (HELCOM), and the organisation Vision and Strategies around the Baltic Sea (VASAB) with a regional development and planning perspective (Moodie et al. 2019). Many countries have ministry representatives or regional authority representatives in both organisations, including Russia and Norway, the latter of which is not a part of but borders the Baltic Sea Region (Kull et al. 2019).

In 2007, HELCOM produced the Baltic Sea Action Plan (BSAP) towards good environmental status in the Baltic Sea, adopted by all Baltic Sea countries including the non-EU-member-country Russia (Kull et al. 2019). The Baltic Sea is both brackish and semi-enclosed with land, which causes the sea basin to experience a limited water exchange and be very sensitive to pollution and environmental pressures from human activities also on land (HELCOM 2010). The BSAP was implemented to target many of the environmental problems in the Baltic Sea such as eutrophication, hazardous substances, loss of biodiversity etc. to reach good ecological status by 2021 (HELCOM 2007).

In 2010, the two organisations of HELCOM and VASAB joined forces in a joint HELCOM-VASAB MSP Working Group that coordinates ecosystem-based terrestrial and marine spatial planning as part of The Horizontal Action of the European Union Strategy for the Baltic Sea Region (EUSBSR) (Moodie et al. 2019). The working group developed 10 principles/guidelines also in 2010 to support the implementation of MSP in the Baltic Sea region (HELCOM-VASAB 2010). Due to the many similarities between the guidelines and the minimum MSP requirements in the MSP Directive, they too seem to lack detailed instructions for practical implementation. Therefore, the various international MSP projects such as the ones presented in Table 1 are useful to develop coveted MSP experience and MSP advice for Baltic Sea planners regarding how to cooperate successfully across the Baltic Sea countries (Kull et al. 2019). The projects included in Table 1 make up a full list of all Baltic Sea projects that have generated knowledge of direct relevance for this thesis.

Table 1. List of international Baltic Sea MSP projects of direct relevance for this thesis. Relevance is illustrated with colour: Green: thesis-related collaboration. Light blue: Conflict-synergy knowledge inputs to thesis. Dark blue: GIS data inputs to thesis. This table continues pp. 11-13.

Project	Description
SEAPLANSPACE (2014–2020) INTERREG South Baltic Programme 2014-2020	Project title: *Marine spatial planning instruments for sustainable marine governance* Countries: Denmark, Germany, Lithuania, Poland, and Sweden. Webpage: https://seaplanspace.eu/ A focus on cross-border MSP training and networking to increase the quality and quantity of the Baltic Sea MSP labour force, including local/regional authorities, universities, businesses etc.
BONUS BASMATI (2017–2020) BONUS Programme 2017–2020 (Blue Baltic) Partly financer of this PhD.	Project title: *Baltic Sea maritime spatial planning for sustainable ecosystem services* Countries: Denmark, Finland, Germany, Latvia, and Sweden. Webpage: https://bonusbasmati.eu/ A major outcome will be the Baltic Explorer, a spatial decision support system designed to facilitate interactive MSP by enabling cross-border collaboration and stakeholder involvement.

Plan Bothnia (2010–2012) EU DG Mare – European Integrated Maritime Policy	Project title: *Planning the Bothnian Sea* Countries: Finland and Sweden. Coordinated by the HELCOM Secretariat. Webpage: http://www.helcom.fi/helcom-at-work/projects/completed-projects/plan-bothnia The Bothnian Sea area between Sweden and Finland as a Baltic transboundary MSP case study.
COEXIST (2010–2013) the European Community's 7th Framework Programme (FP7/2007-2013), grant agreement no 245178	Project title: *Interaction in European coastal waters: A roadmap to sustainable integration of aquaculture and fisheries* Baltic Sea countries: Denmark, Finland, and Germany. Coordinated by Institute of Marine Research (IMR), Norway. Webpage: https://www.coexistproject.eu/ Results include maps and materials about marine use interactions in European coastal waters, for aquaculture and fisheries.
PartiSEApate (2012–2014) INTERREG IV B: Baltic Sea Region Programme 2007–2013	Project title: *Multi-Level Governance in MSP throughout the Baltic Sea Region* Baltic Sea countries: Germany, Latvia, Lithuania, Poland, and Sweden. Webpage: http://www.partiseapate.eu/ Results included instruments for how MSP multi-level governance mechanisms can be realised in the Baltic Sea region such as land-sea integration, transnational consultation, ecosystem-based approach, stakeholder participation.
Baltic Scope (2015–2017) Directorate-General for Maritime Affairs and Fisheries (DG MARE)	Project title: *Towards coherence and cross-border solutions in Baltic Maritime Spatial Plans* Countries: Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, and Sweden. Webpage: http://www.balticscope.eu Bringing together national authorities with a planning mandate to collaborate in a transboundary Maritime Spatial Planning setting, focusing on energy, environment, fisheries, shipping, knowledge sharing, and a pan-Baltic ecosystem-based approach.
MUSES (2016-2018) EU HORIZON 2020	Project title: *Multi-use in European Seas* Baltic Sea countries: Denmark, Estonia, Finland, Germany, Latvia, Poland, Russia, and Sweden. Webpage: http://muses-project.com Results include a final project report on multi-use potentials within Europe including the Baltic Sea region.

Nordic Blue Parks (2011) Nordic Councils of Ministers	Project title: *Nordic Blue Parks* Countries: Denmark, Finland, and Sweden. Coordinated by the Finnish state company Metsähallitus. Webpage: http://www.unesco.org/new/en/culture/themes/underwater-cultural-heritage/divers/nordic-blue-parks/ Guidelines and criteria for sustainable blue trails, meaning underwater nature and cultural trails for tourism purposes.
Baltic Blue Growth (2016–2019) INTERREG V B: Baltic Sea Region Programme 2014–2020	Project title: *Initiating full scale mussel farming in the Baltic Sea* Countries: Denmark, Estonia, Germany, Latvia, Poland, and Sweden. Webpage: https://www.submariner-network.eu/balticbluegrowth Baltic Blue Growth established fully operational mussel farms to counteract eutrophication and create new blue growth opportunities.

1.1.4. An untapped potential of spatial decision support tools in MSP

Due to the strong spatial-temporal character of MSP, the assistance of spatial decision support tools (DSTs) are important means in the implementation of MSP (Pınarbaşı et al. 2017; Stelzenmüller et al. 2017). DSTs are software-based tools to support evidence-based decision-making (Pınarbaşı et al. 2017), and they are interactive (Janssen et al. 2015; Alexander et al. 2012).

Due to their interactivity, they can support stakeholder involvement in MSP (Munro et al. 2017). It can either be directly by enabling the end-users to be stakeholders or through a facilitator appointed to navigate the tool on behalf of the stakeholders (Rönneberg et al. 2019). The target groups of MSP-relevant DSTs can be made up by one or more types of end-users/stakeholders, for example, MSP planners, scientists, MSP sector representatives, NGO's, citizens etc. (Pınarbaşı et al. 2017).

Spatial DSTs use maps as the means of communication between stakeholders and users (Janssen et al. 2015). As the UNESCO guide to MSP revealed (Ehler & Douvere 2009), many of the sub-steps of MSP involve mapping. Spatial DSTs can assist MSP with maps highlighting current and future scenarios and trade-off challenges to be explored and discussed by relevant MSP stakeholders (Gee et al. 2019; Kull et al. 2019; Moodie et al. 2019). They often need GIS datasets with bio-physical, socio-economic, cultural, administrative, resource-related information (Stelzenmüller et al. 2017; Schucksmith et al. 2014). They do not have to support all stages of MSP decision-making but can for example focus on, for example, data and information handling, analysis, and/or storage. In fact, it is an advantage when DSTs are specific about their strengths and limitations since it seems impossible to develop one tool for all steps of MSP (Pınarbaşı et al. 2017).

A trend seems to be that DSTs are not included very often in actual MSP. Instead, pilot projects are more likely to include DSTs due to less time pressure and more financial resources. This point was made by Pınarbaşı et al. (2017) based on a review of 34 DSTs, whereof most were spatial DSTs. The DSTs were applied in 29 different marine spatial plans or MSP initiatives, whereof some took place in the Baltic Sea. The review by Pınarbaşı et al. (2017) illustrates some gaps of existing spatial DSTs.

1.1.4.1. Recommended functionalities for MSP-supporting spatial DSTs

The DST analysis by Pınarbaşı et al. (2017) illustrates that challenges need to be overcome for spatial DSTs to be better included in actual MSP. Thus, there is a need to improve existing spatial DSTs and to develop new spatial DSTs to fill out existing functionality gaps. Recommendations based on academic literature to future spatial DSTs include:

Recommendations on user ease:

- *R1: Document the tool well and ensure that it is working*. To encourage trust and credibility, spatial DSTs should be demonstrated to work prior to being fully handed over to stakeholders. Their results should be reproducible, and they should be well-documented and well-tested (Bagstad et al. 2013).
- *R2: Prioritise a simple design, train users when necessary, and optimise processing time*. Complicated spatial DSTs require more specialised users which makes such tools more difficult to include in actual MSP. Therefore, a simple interface is an advantage, and it is important to train the tool target group in how to use the tool if it is complicated (Pınarbaşı et al. 2017). Furthermore, the tool should not take too long to run (Bagstad et al. 2013). Consideration should also be given to minimise the time it takes to gather and prepare data, since time-consuming data processes can take focus away from planning (Pınarbaşı et al. 2017).
- *R3: Aim for multifunctionality*. A need exists for more multifunctional tools (Pınarbaşı et al. 2017). The multifunctionality does not have to be due to one tool but can be a package of tools that enable users to easily use more tools in order to cover more steps of MSP, since it is hard to include all possible MSP-relevant functions in just one tool (Pınarbaşı et al. 2017). Another way of ensuring multifunctionality is to combine quantitative information with qualitative expert knowledge to integrate different knowledge sources (Ruiz-Frau et al. 2015).

Recommendations on tool accessibility:

- *R4: Maintain spatial DSTs and make them freely available for users also at longterm scale*. It is a problem that many spatial DSTs are not maintained by developers and stop being available after a certain time, turning them into scientific experiences instead of becoming applied tools (Pınarbaşı et al. 2017). By creating spatial DSTs as open source tools, not only the tool but also the code behind the tool can be made available for other developers to evaluate and extend (Depellegrin et al. 2017; Menegon et al. 2016).

- *R5: Minimise license costs***.** Commercial licenses can limit the number of tool users due to financial reasons (Pınarbaşı et al. 2017).

Recommendations on transparency:

- *R6: Prioritise transparency of tool calculations to avoid black box user experiences***.** By designing interactive spatial DSTs with transparent, systematic, flexible approaches that are easy-to-follow for users, the users might avoid viewing spatial DSTs as *"black box"* calculations, meaning program calculations that they do not understand due to *"little ability to trace decisions back to the individual information sources"* (Collie et al. 2013).
- *R7: Include uncertainty analysis*. Instead of only providing single value results, it was recommended through interviews with 77 American ecosystem services analysis practitioners to include uncertainty approaches such as Monte Carlo Simulation or Bayesian Network Modelling in spatial DSTs (Bagstad et al. 2013). Uncertainty analyses are defined to be analyses that explore how uncertainties of different inputs to a model lead to overall uncertainty in the results of the model (Lilburne and Tarantola, 2009). Following the previously mentioned description of *"black box"* calculations from Collie et al. (2013), uncertainty analysis can be argued to support transparency through its ability to facilitate tracing outputs back to inputs.

Content-based recommendations:

- *R8: Include economic and social analysis*. Since it is ideal to balance environmental, social, and economic interests in MSP, it is a challenge that many existing spatial DSTs tend to only focus on environmental issues according to the review by Pınarbaşı et al. (2017). Therefore, a need exists for including socio-economic aspects in spatial DSTs (Pınarbaşı et al. 2017).
- *R9: Include and support stakeholder participation.* A need exists for including stakeholder engagement/feedback to solve conflicts and better target also the later stages in MSP that include MSP monitoring, evaluation, and adaptation (Pınarbaşı et al. 2017). Furthermore, expert knowledge/stakeholder values and negotiation processes can advantageously be included in spatial DSTs to better consider stakeholder participation (Janssen et al. 2015; Ruiz-Frau et al. 2015).
- *R10: Consider future scenarios and the spatial-temporal dynamics of oceans.* Especially the temporal aspect is lacking in existing spatial DSTs, creating a need to learn from historical data about the future and to consider changing conditions for alternative future scenarios. By including the temporal dimension, *"potential future conflicts may be highlighted prior to their development"* (Pınarbaşı et al. 2017). In addition, DSTs that are applicable to different spatial scales are more attractive for decision-makers (Bagstad et al. 2013)

1.1.5. Co-location challenges

Various studies highlight the increasing tendency for environmental, socio-economic, cultural, and location-based conflicts between marine uses, and thus a growing need to solve conflicts (Klinger et al. 2018; Tsilimigkas & Rempis 2017; Kyriazi et al. 2017). Such conflicts should be resolved as early in the planning process as possible (Christie et al. 2014). Recent literature highlights the need for finding and strengthening synergies between marine uses when possible, for example, Schupp et al. (2019), Depellegrin et al. (2017), Stelzenmüller et al. (2017), and Papageorgiou (2016). Spatial DSTs could advantageously support such efforts due to the spatial-temporal characteristics inherent in pointing out use-use synergies and conflicts.

Both use-environment interactions as well as use-use interactions are important for MSP (Rempis et al. 2018; Stuiver et al. 2016; Kannen 2014; Christie et al. 2014). Some existing spatial DSTs focus on use-environment interactions, for example, the cumulative environmental impact assessment (CIA) approach implemented into tools such as Symphony (Hammar et al. 2020), MYTILUS (Hansen 2019), and EcoImpactMapper (Stock 2016). Other existing spatial DSTs focus on space allocation, for example, Marxan With Zones (Watts et al. 2009). Another group of existing spatial DSTs focus on modelling use-use conflicts with proxy data, for example, the Adriplan Conflict Score Tool (Depellegrin et al. 2017). However, no existing spatial DST seems to focus directly on use-use interactions to increase synergies and minimise conflicts, as argued in *Bonnevie et al. (2019)*.

The introduction of MSP in this thesis has painted the picture of MSP as an ambitious process towards sustainably balancing blue growth interests with environmental preservation needs of ecosystem services in an increasingly competitive ocean environment, handling the management of many sectoral interests at once (co-location), while allowing variation among countries. For co-location to be successful, it requires a sea-basin-based, sustainable approach that includes consideration of both the economic MSP pillar and the environmental MSFD pillar in order to balance competing claims for marine space, while avoiding too high cumulative pressures on the environment (Hansen 2019; Gimpel et al. 2018; Klinger et al. 2018).

Despite the direct reference to co-location in the MSP Directive, no clear, widely acknowledged definition or framework seems to exist describing co-location, as argued in *Bonnevie et al. (2019)*. Many interlinked concepts exist that refer to the co-location process of locating marine uses in close spatial and temporal proximity when possible while distinguishing conflicting marine uses. Co-location is only one of such concepts, for example, used in Klinger et al. (2018), Tsilimigkas & Rempis (2017), Yates et al. (2015), Zanuttigh et al. (2015), Christie et al. (2014). Other co-location concepts include coexistence (Depellegrin et al. 2017; Kyriazi et al. 2016), co-use (Kannen 2014), multi-use (Depellegrin et al. 2019), multiple use (Ehler & Douvere 2009), and interactions of sea uses (Papageorgiou 2016). Many articles mix the concepts without distinguishing between them, for example, Gimpel et al. (2018), Kyriazi (2018), Stuiver et al. (2016), and Kannen (2014). Existing literature has primarily focused on specific physical combinations of marine uses into multi-use, in particular combinations of aquaculture, fishing, and wind farms (Stelzenmüller et al. 2017; Stuiver et al. 2016; Zanuttigh et al. 2015; Christie et al. 2014; Kannen 2014), but has not given much attention to develop an overall theoretical framework for considering co-location.

To sum up, the growing competition over marine space increases the need for considering co-location within MSP, an aim that is directly stated in the MSP Directive as a requirement for the coastal EU member states to consider in their MSP processes. However, no clear and widely acknowledged co-location framework yet exists, and no existing spatial DST seems to claim to directly facilitate co-location.

1.2. PhD objectives

This PhD project aims at creating an analytical framework and a spatial DST for co-location of marine uses to meet the increasing needs in regards of cross-sectoral, integrative MSP. The geographic focus is on the Baltic Sea region, a region known for its long tradition for international MSP collaboration between its adjacent EU countries.

This thesis postulates that MSP with all its ambitious result-, process-, and data-related goals can lead to better managed marine spaces if clear MSP guides exist that built on best practices including methods to facilitate co-location.

During the PhD study, three research questions were formulated:

1) How to develop an analytical framework for spatial DSTs to assess co-location within MSP?
2) How to design a new spatial DST that attempts to fulfil gaps regarding co-location of marine uses as well as consider functional abilities of user ease, tool accessibility, and transparency?
3) How can such a new spatial DST for co-location support different dimensions of integrative MSP?

The research questions (RQs) supplement each other, but they also serve as steppingstones for each other: RQ2 depends on findings from RQ1, and RQ3 depends on findings from RQ2. They are visualised together with relevant sub-problems and research tasks in Figure 5.

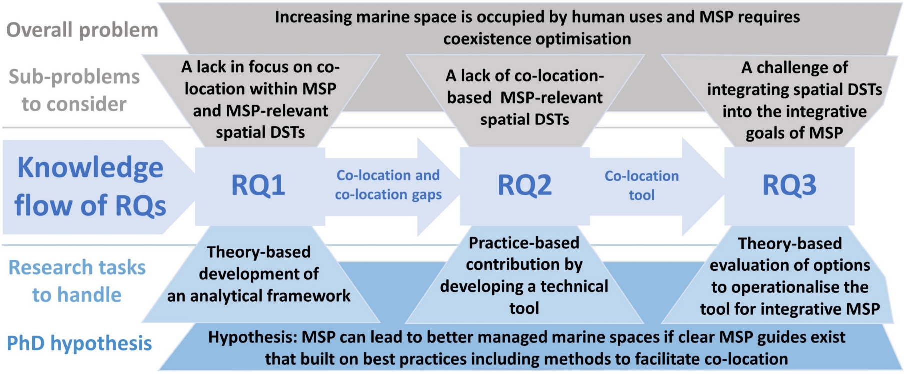

Figure 5. Knowledge flow of research questions (RQs). The flow is linked to problems, sub-problems, research tasks, and PhD hypothesis.

DSTs are not always spatial, but only spatial DSTs are considered in this research, since the spatial dimension is needed, as per definition, for supporting maritime *spatial* planning, and since co-location is a spatial challenge. Non-spatial DSTs might still support other non-spatial parts of MSP, although they are not a focus in this research.

1.2.1. Expected significance and outcome

This research aims to provide an improved methodology on how to detect current conflicts and synergies between marine uses, and how to minimise the former and strengthen the latter in future planning scenarios within MSP. For the Baltic Sea, it will also contribute with an evaluation of which marine uses at a general level that either collaborate well, co-exist well, or conflict with other marine uses according to existing Baltic Sea knowledge. Its insights were intended to contribute to BONUS BASMATI, an international EU project that has partly financed this research. This research has not directly participated in the three official BONUS BASMATI case studies (a pan-Baltic case, a Danish-German case, and a Latvian case), but its findings constitute an independent part of the pan-Baltic case, hopefully contributing to increased pan-Baltic collaboration and providing inspiration to marine spatial planners for how to better consider co-location within MSP. While the focus is on the Baltic Sea, it is the ambition that the framework and spatial DST should be applicable to some degree in other marine areas.

1.3. Thesis structure, research structure, and paper order

Figure 6 shows the structure of this thesis with considerations of RQs, the research structure including methods, and the list of PhD papers including BONUS BASMATI contributions, and how they all relate to each other.

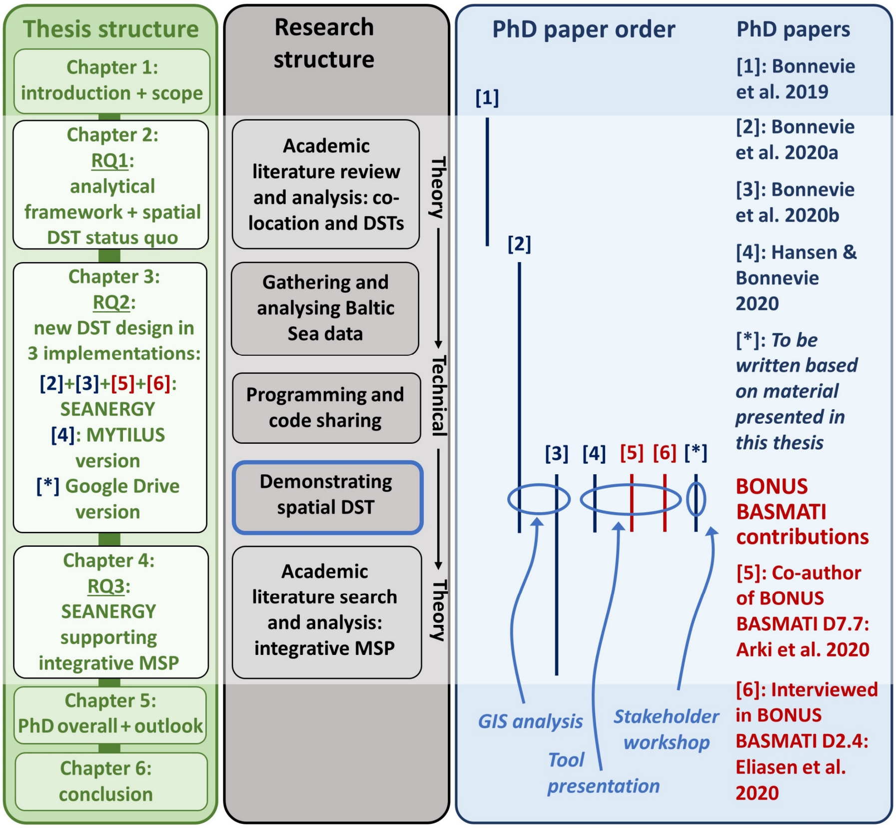

Figure 6. Thesis structure, research structure, and PhD paper order. Each structure is showed vertically, and it is visualised horizontally how they are linked together.

The thesis structure in Figure 6 shows how this thesis will move on in the next chapters to dedicate a chapter to each RQ. Chapter 2 focuses on the analytical co-location framework and analyses the ability of existing spatial DSTs to consider co-location (RQ1). Chapter 3 presents a new spatial DST approach for co-location and three different implementations of it (RQ2). Chapter 4 draws on the background material on MSP and spatial DSTs to evaluate the degree to which the new spatial DST facilitate integrative MSP (RQ3). Chapter 5 reflects on the main contributions of this research, and it states suggestions for further research. Chapter 6 presents the conclusion.

The research structure follows the RQs and thus the thesis structure. The research structure moves from theoretical literature study, to implementing technical spatial DST, to theoretical literature study. This enables the *practical* RQ2 to be founded in a *theoretical* RQ1 as well as contributing to a *theoretical* RQ3. The practical spatial DST contribution consists of three different implementations: SEANERGY, MYTILUS, and a Google Drive version. The research methods (including the implementations) are more fully explained in the beginning of their corresponding RQ-based thesis chapter.

The PhD paper order follows the RQs to a certain degree and thus the thesis structure. Paper 1 *Bonnevie et al. (2019)* provides answers to RQ1 and constitutes the main material behind Chapter 2. Paper 2 *Bonnevie et al. (2020a)* provides answers to RQ2, making up the main material for Chapter 3, which also draws a little on Paper 3 *Bonnevie et al. (2020b)* and Paper 4 *Hansen & Bonnevie (2020)*. Paper 3 *Bonnevie et al. (2020b)* mostly provides answers to RQ3, and this paper is thus the main source for Chapter 4. Furthermore, Figure 6 acknowledges how this research has contributed to BONUS BASMATI deliverables. Additional findings from a SEAPLANSPACE stakeholder workshop will be presented in this thesis but have not yet been synthesised into a paper. The stakeholder workshop findings are partly presented in BONUS BASMATI deliverable 2.4 by Eliasen et al. (2020), for which reason this thesis actively includes this reference. Despite not being an author of Eliasen et al. (2020), most of the SEANERGY-specific reflections in the report have been provided by this author through an interview where NORDREGIO collected information on SEANERGY. A small part of it reflects observations made by NORDREGIO that observed the use of SEANERGY in the workshop.

This thesis includes literature which is not applied in the papers, for example, linking the co-location framework presented in Chapter 2 to Hägerstrand's Time Geography concept (1970) but only to provide a wider perspective on the contributions of the papers.

Chapter 2.
Analytical co-location framework to reveal spatial DST gaps

To enable a better spatial DST-based focus on co-location in MSP, it is important to understand how to approach co-location through an analytical framework for spatial DSTs (RQ1). Such a framework can be used to assess to what degree existing spatial DSTs consider co-location. To meet these tasks, this chapter sums up knowledge from Paper 1 *Bonnevie et al. (2019)*, available in Appendix D, and links knowledge presented in Paper 1 to Hägerstrand's Time Geography concept (1970) and to distributional aspects of social justice.

2.1. A literature review

The main method behind this chapter is a systematic academic literature review that was carried out in the beginning of this research, contributing to Paper 1. A snowball method was applied consisting of the fact that four themes of search words were gradually gathered and expanded whilst browsing through co-location-related literature. The themes are summed up in Table 2. The individual search words were used in various multi-theme search combinations. Only the search words of theme 3, that describe specific co-location cases, were used in single word searches due to their smaller topic span.

The decision was made to only focus the literature review on academic articles, and the publication period was set to all publications published in 2010 or later. Since the literature review was finalised in the beginning of September 2018, it limited the publication period to 2010 (including whole year) to 2018 (including August).

The search results were ordered after a built-int relevance criterion of the advanced search functions of the databases used: Aalborg University Library's advanced online search function (aub.aau.dk), and the SCOPUS database. For each search result, the titles of the first 50-300 articles were browsed for relevance: 50 if the search combination gave few relevant title results, and 300 if many relevant titles were found. When a title was found relevant for the PhD topic, its corresponding article abstract was explored. If the abstract was found relevant, the article was downloaded for further consideration. When a new relevant search word in an article was encountered, it was added to the search word list. An additional snowball technique was used in that the literature lists of relevant articles were explored for further articles and other publications of interest, enabling the final list of references, included in the review, to cover three publications published earlier than 2010, and three non-peer-reviewed international MSP project reports. Furthermore, one article is from 2019, since it was added based on a recommendation from a peer-reviewer of Paper 1.

Even though *conflict* is a search word that was applied in the literature review, a selection process was carried out where the literature that ignores spatial compatibility and/or synergies, but only focuses on marine use conflict resolution and/or only focuses on conservation conflicts (use-environment interactions), was evaluated to be out of scope. Furthermore, some literature sources were left out due to redundancy: For example, Menegon et al. (2016) and Menegon et al. (2018b) were left out, since they describe the same tool as Depellegrin et al. (2017) but with less detail. As a result, 32 publications were included in the final review, making up the literature list of Paper 1.

Table 2. Search words used in various multi-theme search combinations in the literature review. The literature review provided inputs to Paper 1. The search words of theme 3 that describe specific co-location cases are also applied in single word searches.

Theme 1: Ocean	"marine spatial planning" / "MSP" / "maritime spatial planning" / "marine" / "integrated coastal zone management" / "ICZM" / "ocean*" / "blue growth".
Theme 2: Co-location	"co-locat*" / "colocat*" / "co-exist*" / "coexist*" / "co-use*" / "couse*" / "multi-use*" / "multiuse*" / "multiple-use" / "multiple use*" / "sea use*" / "synerg*" / "conflict*" / "use-use".
Theme 3: Co-location sub-themes	"artificial reef*" / "mussel*" / "seaweed*" / "cruise ship*" / "touris*" (as in e.g. tourism) / "maritime cluster*" / "decommission*".
Theme 4: Spatial DSTs	"GIS" / "spatial tool*" / "spatial decision support tool*" / "spatial DST*" / "decision support system*" / "SDSS" / "multicriteria" / "map*".

2.2. An analytical co-location framework for spatial DSTs

A presentation of the key elements of the co-location framework deduced in Paper 1 is provided here.

2.2.1. A co-location definition

Paper 1 describes how no single terminology exists which provides a clear definition of the co-location concept. It argues about how different academic publications use different concepts such as co-location, coexistence, co-use, multi-use, multiple use, and interactions of sea uses. Paper 1 draws on findings from the EU Horizon2020 MUSES project to define multi-use as *"the joint use of resources in close geographic proximity"* which *"can involve either a single user or multiple users performing multiple uses"* (Depellegrin et al. 2019), and to define a use as *"a distinct and intentional activity through which a direct (e.g. profit) or indirect (e.g. nature conservation) benefit is drawn by one or more users"* (Depellegrin et al. 2019). From this perspective, multi-use is a very strong case of co-location where marine uses benefiting from the sea are not just located in close spatial-and-sometimes-temporal proximity but are actively sharing resources and thus experiencing synergies. The definition of resources is also derived from Depellegrin et al. (2019): *"The good or service that represents a value to one or more users. Such a resource can be biotic (e.g. fish stocks) or abiotic (e.g. ocean space) and can be exploited through either direct (e.g. fishing) or indirect (e.g. nature conservation) uses."*. A more narrow, passive definition of co-location is introduced in Paper 1 by referring to the concept of spatial compatibility as defined by Kannen (2014) which aims to avoid negative impacts from marine uses on each other, but which ignores synergies. While spatial compatibility does not focus on synergies, it does however, describe the ability of marine uses to exist in the same spatial horizontal spot. Paper 1 points out that a focus on synergies has often been ignored in MSP while a focus on conflicts has dominated, which has urged Klinger et al. (2018) to introduce a more nuanced scale for describing use-use interactions going from competition in one end to mutualism in the other end. The scale is reproduced in Paper 1 where it is linked to a conflict-synergy scale: Commensalism and mutualism are synergies, since they benefit at least one interacting marine use without causing any negative impacts, whereas amensalism, antagonism, and competition are conflicts, since they cause negative impacts to at least one other marine use.

To embrace the full conflict-synergy scale, while acknowledging the MUSES definition of multi-use, a co-location definition derived from the co-location arguments stated in Paper 1 is as follows:

Co-location is:

- The process of understanding/exploring conflicts and synergies between marine uses arriving from spatial-and-sometimes-temporal proximity *and;*
- the process of using that understanding to increase synergies at sea by placing marine uses into coexistence in close spatial-and-sometimes-temporal proximity when possible while minimising/avoiding conflicts at sea by separating marine uses when it is not possible.

The co-location definition captures why co-location is important for MSP to be able to strengthen synergies and minimise/avoid conflicts. It furthermore reflects an important aspect of the conflict-synergy scale that no neutral interactions exist. Use-use interactions constituting synergies or conflicts will always include benefits and/or negative impacts related to resources, as per definition. As Paper 1 demonstrates, the types of resources being shared or positively/negatively affected vary with the involved types of spatial-temporal use-use links.

2.2.2. Spatial-temporal links between interacting marine uses

Based on the academic literature review of co-location, four types of spatial-temporal links between interacting marine human uses are deduced in Paper 1:

- *Location links*: the spatial-temporal resource links between marine uses that influence the extents-and-durations of marine uses.
- *Environmental links*: interactions where environmental processes/by-products caused by one or more marine uses negatively/positively affect other marine uses due to spatial-temporal proximity.
- *Technical links***:** the spatial-temporal resource links between marine uses that concern infrastructure, tools, and safety.
- *User attraction links*: interactions where spatial-temporal proximity between marine uses positively/negative affects the user attraction level of one or more of the marine uses.

As described in Paper 1, the links have a significant resemblance to the four types of multi-use resources mentioned in Appendix A of the EU MUSES project, these are geographical, biological, physical, and human resources, respectively (Depellegrin et al. 2019). However, instead of being resources, the spatial-temporal links constitute *resource links* through which marine uses affect the resource needs of each other either negatively (conflicts) or positively (synergies). Such resource links are important to investigate with the purpose of exploring the resource foundations for potential conflicts and synergies. All four link types do not necessarily exist for all marine use combinations. In addition, they can exist alone or in combinations. However, the links provide a checklist for what types of interactions to search for when exploring use-use interactions to assess co-location options, an important part of the ambitions of MSP. Furthermore, their spatial-temporal character illustrates that it is a necessity to consider both temporal attributes of marine uses and their location in vertical and horizontal space to fully explore positive/negative spatial-temporal links of marine uses. Paper 1 provides systematic examples of the four link types together with potential conflicts and synergies that they produce according to the academic literature review, and Figure 7 summarises these examples.

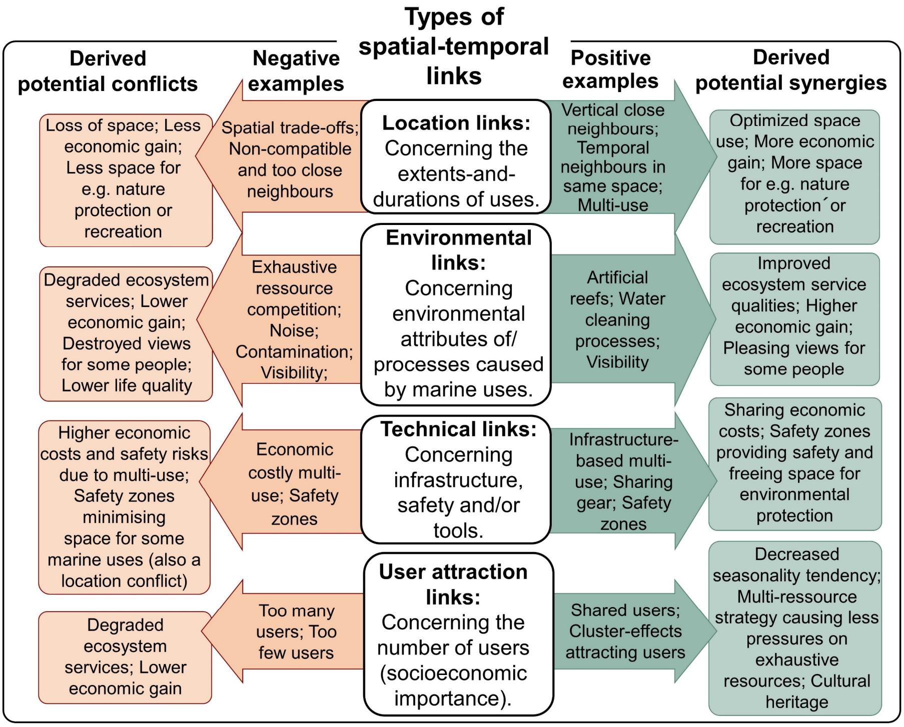

Figure 7. Spatial-temporal link examples. The examples include derived potential conflicts and synergies. They summarise knowledge from Bonnevie et al. (2019).

The examples in Figure 7 indicate that the size of the spatial-temporal proximity can vary from example to example. The proximity can be relatively fixed in space while spanning short time differences through mobile marine uses overlapping or spanning longer time with seasonal marine use changes. In other cases, it can be relatively fixed in time while spanning smaller horizontal spatial spots through technical multi-use constellations or spanning larger horizontal spatial distances, for example, through visibility links between bathing and wind farms. The positive examples span over synergies provided through *resource links*, for example, artificial reef effects benefitting nearby fishing, to synergies provided through *resource sharing*/multi-use. The positive examples furthermore show that multi-use links can either be strong and active, for example, the technical multi-use of wind farms combined with aquaculture, or more passive, for example, the sharing of space through vertical divisions of the water pillar such as pipelines at the bottom with sailing at the surface. Figure 8 visually illustrates specific examples of each spatial-temporal link type.

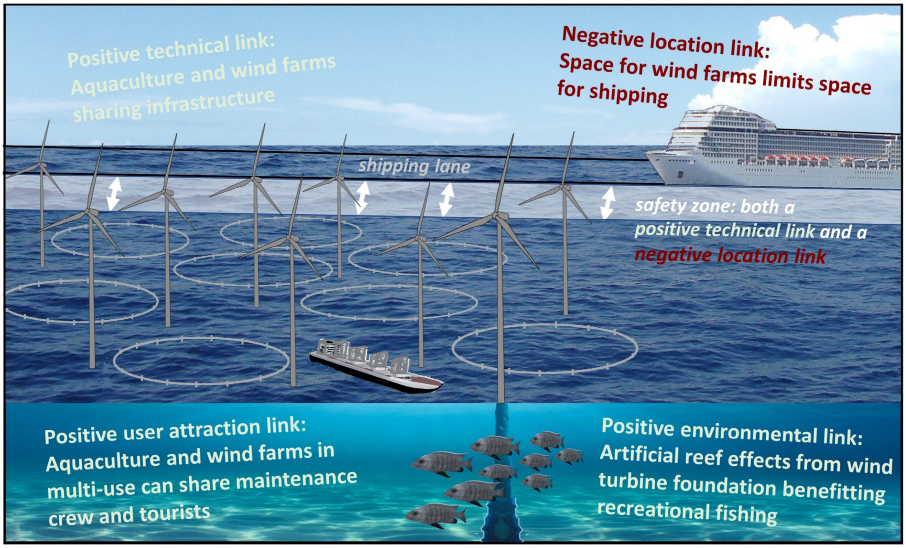

Figure 8. Visual examples of spatial-temporal links. This figure summarises knowledge from Bonnevie et al. (2019) by visualising a specific example of each of the four spatial-temporal link types.

2.2.3. Co-location linked to use-environment interactions

Paper 1 focuses on use-use interactions but argues how use-environment interactions are also important for a full co-location perspective. Even though the environmental links of the deduced spatial-temporal use-use links have a clear overlap with use-environment interactions, Paper 1 points out how, for example, economic, location-based use-use synergies can sometimes constitute use-environment conflicts. Human uses are not always compatible with the needs of nature (Hansen 2019). On one hand, Paper 1 asserts that analyses of use-use interactions to some extent can enable options to balance nature/environment protection and marine use interests by including protected areas as part of the marine use definition when discussing use-use interactions. On the other hand, Paper 1 recommends supplementing a focus on use-use interactions with knowledge from cumulative impact assessments (CIA) that assess cumulative impacts from human pressures on the environment to enable synergic marine uses to coexist if their cumulative pressures on the environment do not get too high.

2.2.4. Co-location linked to MSP

Besides linking co-location to spatial-temporal use-use interactions and use-environment interactions, Paper 1 links co-location to the MSP process. The starting point is the general guide with specified steps for how to do MSP by Ehler & Douvere

(2009). Since conflict management has a longer tradition than synergy studies within MSP, three conflict management stages have already been deduced by Kyriazi (2018) and linked to the Ehler & Douvere MSP steps. Paper 1 transforms these conflict management stages into co-location management stages by adding a focus on synergies: 1) detect spatial compatibilities, conflicts, and/or synergies, 2) prevent conflicts and increase synergies, and 3) minimise conflicts when they cannot be avoided and increase synergies.

Paper 1 points out how the three co-location management steps support a spatial marine use scenario-based approach that facilitates introducing use-use synergies and conflicts into scenario creation as well as scenario comparison. A fitting definition of a spatial marine use scenario in this context can be provided by referencing to the MSP step-by-step guide by Ehler & Douvere (2009): *"A spatial sea use scenario provides a vision that projects the future use of marine space based on a core set of goals, objectives, and assumptions about the future"*.

2.2.5. An analytical co-location framework for spatial DSTs

The combination of all presented use-use interaction aspects results in a stepwise use-use interaction framework present in Paper 1 with a twofold purpose; it can be used to evaluate to which degree that existing spatial DSTs consider use-use interactions, and it can be used to create new spatial DSTs that assist co-location assessments. Paper 1 recommends incorporating a focus on balancing nature/environment protection with marine use interests and thereby expand the framework to a co-location framework. Such an addition has been provided here, for which reason an updated version of the framework is presented in Figure 9.

Figure 9 contains four steps that spatial DSTs need to include to facilitate the assessment of co-location: 1) spatially-temporally locate use-use interactions, 2) list their synergies and conflicts, and 3) weight/rank their synergies and conflicts, and an additional step 4) to balance blue growth interests with environmental/nature protection needs. The different shades of grey colour for each step represent different detail levels: the darker the grey, the more details are included. While the first three steps only consider use-use interactions, the last step considers use-environment interactions, all necessary steps to not only detect conflicts/synergies but also to increase the former and minimise the latter through a spatial marine use scenario-based approach (Bonnevie et al. 2019).

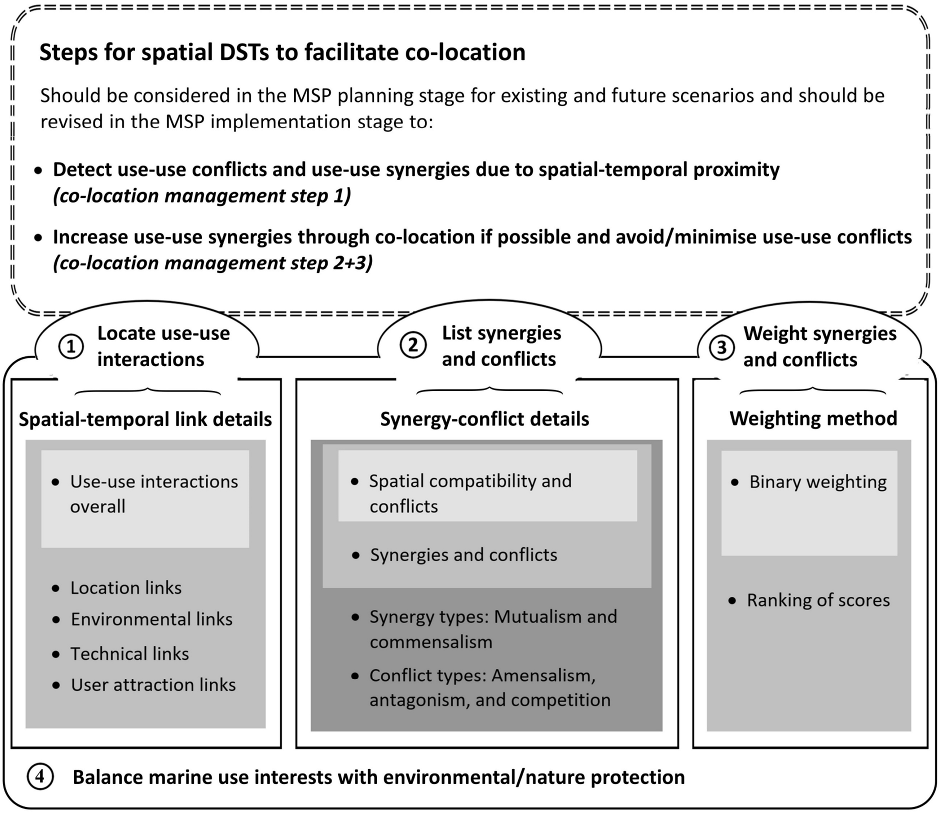

Figure 9. A stepwise co-location framework. Its purpose is to guide spatial DSTs to facilitate co-location. This figure is adjusted from Bonnevie et al. (2019).

2.3. Co-location with existing spatial DSTs

Paper 1 illustrates how the stepwise use-use interaction framework advantageously can be used to analyse the degree to which existing spatial DSTs target use-use interactions and thereby facilitate co-location. Paper 1 asks the following questions based on the use-use interaction framework:

1) Which co-location management stages do existing use-use interaction-relevant spatial DSTs target?
2) Do they only consider spatial compatibility and conflicts, or do they also consider synergies?
3) Do they use a binary or ranking-based method for weighting?
4) To which degree do they consider the four different spatial-temporal link types of use-use interactions?

With the extended stepwise co-location framework, one can add a fifth question which Paper 1 only partly explores due to the question being related to use-environment interactions:

5) How do the use-use interaction-relevant spatial DSTs balance marine use interests with environmental protection needs in their co-location considerations?

2.3.1. Assessing use-use interactions with existing spatial DSTs

Two groups of existing spatial DSTs with use-use relevance are deduced in Paper 1 from the reviewed co-location literature: these are matrix-and/or ranking-based tools and space allocation tools, respectively. The former group can be useful for detecting conflicts and synergies (co-location management stage 1), and the latter group can be useful for operationalising the knowledge from the first type of tools to co-locate compatible uses and separate conflicting ones as part of the allocation of space to different marine uses (co-location management stage 2+3).

As described in Paper 1, the matrix- and/or ranking-based approaches can be useful to systematically gather and explore existing conflict-synergy knowledge. However, most of them lack a focus on synergies, and only some of them do to a small degree consider location links, environmental links, and user attraction links whereas none of them consider technical links. Furthermore, most of them are neither software-based nor spatial but could advantageously be combined with spatial information to explore the conflict-synergy knowledge on maps. They often only consider a binary scoring system instead of actively ranking synergies and/or conflicts. Exceptions to the binary approach is the ability of some approaches to rank specific co-location scenarios based on pre-selected criteria. However, such specific approaches are not systematic investigations of all potential use-use interactions. The Adriplan conflict score tool, as introduced in Depellegrin et al. (2017), based on methodology from the international EU-financed research project COEXIST, manages to go beyond a simple binary approach while taking a more systematic and spatial approach to potential use-use interactions. As Paper 1 points out, a key advantage of the Adriplan conflict score tool is its ability to consider spatial-temporal dynamics and thus location links. It considers spatial compatibility by defining expected conflicts to be actual overlaps in horizontal space, vertical space *and* time, by distinguishing between mobile uses, static uses, and uses in the benthic environment/whole water column/water surface. However, as Paper 1 also points out, the Adriplan conflict score tool does not despite its name enable actual explorations and rankings of conflicts, since it expects all pairwise spatial-temporal overlaps to be conflicts, and thus does not explore whether marine uses neutrally coexist, provide mutual synergies, or really conflict with each other. The only evaluated spatial tool that enables a focus on synergies is the AquaSpace tool, as introduced in (Gimpel et al. 2018). However, as Paper 1 points out, it does not rank the synergies found, and even though it ranks conflicts on a non-binary scale for specific aquaculture types, its resulting binary maps only shows the presence of conflicts without distinguishing between the different conflict levels.

Strengths and limitations regarding the ability to consider use-use interactions were also found to exist for the other use-use interaction-relevant tool type: space allocation tools. Paper 1 analyses the ability to consider co-location options for two of such tools: Marxan With Zones, as introduced in Watts et al. (2009), and a game theory-inspired cooperative marine spatial allocation process (CMSAP), as introduced in Kyriazi et al. (2017). Whereas Marxan With Zones is a spatial DST that distributes space to marine uses, thus working with spatial zone patterns, the latter method is not a spatial tool but it has an indirect spatial focus – to pareto-optimally fairly distribute percentages of marine space out on all marine uses that express marine space claims within the area in focus. Summarising from Paper 1, both approaches consider location links to some degree, since they consider multi-use/options to share space, but they do not consider vertical and temporal relations. As argued in Paper 1, the co-location element can be introduced into space allocation within existing spatial DSTs in two ways. One way is an ability which only Marxan With Zones seems to fulfil. Marxan With Zones offers an option to set zone boundary costs to control the tendency for some specific marine uses to be spatially separated caused by a high zone boundary cost and for other marine uses to be spatially concentrated caused by a low zone boundary cost. Paper 1 explains that this option allows the tool user to manage environmental negative/positive links by separating marine uses with environmental negative impacts on each other and aggregate others with positive environmental neighbourhood effects. The other way to introduce co-location elements into space allocation is through introducing pre-defined multi-use zones as a supplement to the individual marine use zones. As Paper 1 explains, this has been done in a Marxan With Zones study by Yates et al. (2015) where they combined pot fishing and renewable energy into multi-use zones in some areas to optimise overall space for fishing in the whole planning area. It has similarly been done in a CMSAP study by Kyriazi et al. (2017), where they combined nature protection with renewable energy into multi-use zone with a 5 % loss in gain for nature protection within those multi-use zones. As the study by Kyriazi et al. (2017) exemplifies, multi-use zones often minimise gain for the marine uses within the multi-use zones but as the study by Yates et al. (2015) points out, multi-use zones can increase gains across the whole planning area. Paper 1 interprets the focus on gain loss due to multi-use within the CMSAP approach to be an indirect consideration of safety zones and thus technical links. Furthermore, Paper 1 highlights how the establishment of multi-use zones require pre-knowledge about which marine uses can be combined into multi-use.

None of the reviewed tools fulfil all the use-use interaction-related details within the stepwise co-location framework, and based on their co-location-related gaps, the following recommendations have been deduced in Paper 1 for future spatial DSTs to consider:

- Explore spatial-temporal links with the purpose of finding sources to potential conflicts and synergies.
- List not only conflicts and spatial compatibility but also synergies.
- Rank conflicts and synergies instead of only listing them by including expert-based knowledge that attempts to consider risks.

2.3.2. Options to balance marine use interests with environmental protection

While Paper 1 presents arguments towards including options to balance marine use interests with nature/environmental protection, it does not examine the degree to which such ambitions are achieved in the spatial DST-related approaches that are evaluated only for their use-use interaction-related abilities, and not for their use-environment-related abilities. A quick examination of all the evaluated approaches reveals that they all consider nature/environmental protection to some degree. The matrix-based approaches of Kannen (2014) and Ehler & Douvere (2009), the Adriplan conflict score tool (Depellegrin et al. 2017), the AquaSpace tool (Gimpel et al. 2018), as well as Kyriazi et al. (2016) all include *marine protected areas (MPAs)* as a marine use category in their use-use investigations. The two space allocation approaches facilitate the spatial distribution of MPAs, illustrated by Yates et al. (2015) and Kyriazi et al. (2017). In fact, the globally acknowledged Marxan With Zones is often characterised as a conservation planning tool indicating its relevance for environmental/nature protection (Watts et al. 2009). In addition, the approaches that rank specific co-location scenarios all consider environmental and natural degradation as factors in their ranking, specifically Kyriazi et al. (2016), Rempis et al. (2018), and Zanuttigh et al. (2015). All tools thus enable answers to the fifth use-environment-related question and follows step 4 of the co-location framework to balance marine use interests with nature protection options to a certain degree. However, as Paper 1 states, such answers might not be enough for assessing potentials for coexistence, for which reason Paper 1 recommends including the CIA approach to better balance marine use interests with environmental protection needs.

To follow that suggestion, the CIA approach is presented here as part of the review of existing spatial DSTs for co-location. The CIA approach is a famous method that enables a use-environment perspective, first introduced by Halpern et al. (2008). The method has since been implemented in different spatial DSTs including Symphony (Hammar et al. 2020), MYTILUS (Hansen 2019), Tools4MSP (Menegon et al. 2018a), and EcoImpactMapper (Stock 2016). It follows a simplified DAPSI(W)R(M) framework being a natural science approach that stops at the *state changes* level (Hansen 2019), leaving impacts on welfare and responses as measures to be studied in more detailed socio-economic analyses (Elliot et al. 2017). The cumulative effect for each raster cell is commonly defined as an additive linear model, with the cumulative effect then being equal to the sum of all environmental impacts from pressures on ecosystem components in that raster cell (Hansen 2019; Stock 2016; Halpern et al. 2008). The additive CIA formula F.CIA to calculate the total cumulative impact I_C for a raster cell as presented in Hansen (2019) is as follows:

$$I_C = \sum_{i=1}^{n} \sum_{j=1}^{m} P_i \cdot E_j \cdot u_{i,j} \qquad [\mathrm{F}.CIA]$$

Each pressure layer P_i is multiplied with each ecosystem component layer E_j and with the corresponding sensitivity score $u_{i,j}$, and afterwards all the multiplications for all pressure-ecosystem pairs are summed together. The CIA main result is a cumulative impact raster-based map that shows where the marine environment is more pressured by human uses and where it is less pressured by human uses (Halpern et al. 2008). As Paper 1 states, if one combines co-location assessments with CIA results, the combined approach facilitates that co-location does not put too much pressures on the ecosystem which is important for taking an ecosystem-based approach to MSP.

2.4. A broader perspective on co-location

To highlight limitations to the stepwise co-location framework, co-location can be approached in a broader light than spatial DSTs enable. Firstly, the strong spatial-temporal dimension of the framework makes it relevant to draw parallels to Hägerstrand's *Time Geography* concept (1970), a concept that has both similarities with and differences to co-location. Secondly, two other aspects of relevance for co-location will be touched upon – non-spatial drivers and barriers of co-location, and considerations of distributional aspects of fairness in MSP.

2.4.1. A resemblance to and difference from Time Geography

Due to the strong spatial-temporal characteristics of the presented framework, the importance of Hägerstrand's famous *Time Geography* concept (1970) cannot be neglected. Hägerstrand considers space-time paths of individuals and the space-time prisms constituting space-time zones that individuals can navigate within under certain constraints (1970). The marine uses in the stepwise framework presented here are considered as coherent entities at a more general level instead of being made up by the spatial-temporal paths of individuals. However, some similarities between the presented co-location framework and Hägerstrand's *Time Geography* concept do exist. Firstly, Hägerstrand's *Time Geography* concept can be acknowledged for having pointed out how space and time are interlinked (Yu 2006). According to Hägerstrand, with his concept of Time Geography, *"we need to understand better what it means for a location to have not only space coordinates but also time coordinates"* (Hägerstrand 1970). A person moves through space through time

(Hägerstrand 1970). At sea, users of especially mobile marine uses experience how time can be converted to space, since it takes time to move through a spatial landscape, enabling co-location of marine uses by sharing the same space at different times. This idea of sharing space at different times is represented in the co-location framework in Paper 1. Secondly, Hägerstrand can be acknowledged for introducing the idea of co-location in both time and space when different human paths spatially-temporally overlap (Hägerstrand 1970). Again, this Hägerstrand idea has been adopted in the presented co-location framework for multi-use constellations that share space *and* time. While Hägerstrand's *Time Geography* concept is more detailed in the sense that it works at an individual interaction level, the co-location framework presented here is more detailed when it comes to the number of spatial-temporal dimensions included. Hägerstrand's concept typically only includes a 2D space with time as the third dimension (Yu 2006; Hägerstrand 1970). At sea, the depth dimension is also very important to consider for co-location (Papageorgiou & Kyvelou 2018; Tsilimigkas & Rempis 2017), creating the need for a 3D space with time as the fourth dimension. Therefore, coexistence in the presented framework also includes cases where marine uses overlap in horizontal space but experience different vertical locations, for example, benthic location of cables and surface locations of hydropower installations. In summary, the co-location concept in Paper 1 is inspired by Hägerstrand's *Time Geography* concept (1970) but generalises it to be for whole marine uses instead of individual people and extends it with an extra dimension to include ocean bathymetry.

2.4.2. Non-spatial drivers and barriers for co-location

While co-location is a spatial-temporal challenge, non-spatial political, legal, socio-economic, technical, and MSP-process-related drivers and barriers exist and influence co-location options, as described in more detail in Paper 1. They cannot all be managed by MSP but should be considered when relevant in MSP. Due to their non-spatial origin, they are out of scope for the presented co-location framework which focuses on spatial DSTs.

2.4.3. Reflections on distributional aspects of fairness in MSP

Frederiksen et al. (n.d.) argue for the importance of considering fairness in MSP in relation to the distribution of benefits when creating maritime spatial plans. While Paper 1 does not comment on fairness, fairness is partly and indirectly considered by the co-location framework through the fact that the framework excludes antagonistic, one-way benefit interactions from being considered synergies. Thus, the framework prioritises distributions of marine space that consider the needs of all marine uses. It is essential in MSP to include perspectives from a high variety of experts and stakeholders to reflect different marine use interests (Depellegrin et al. 2019; Rempis et al. 2018; Ruiz-Frau et al. 2015). However, even when multiple marine use interests are considered, fairness cannot be guaranteed by the co-location framework, since trade-offs often are needed in real-world planning scenarios (Kyriazi 2018; Hooper et al. 2015). Thus, due to the necessity of trade-offs, planners and politicians need to ask when evaluating and comparing scenarios: who benefits and who loses from the changed planning situation? (Frederiksen et al. n.d.; Coccoli et al. 2018; Kyriazi 2018). Thus, while co-location synergies, as per definition, always should attempt to benefit or at least provide no harm to all marine uses involved, the losers/beneficiaries question is crucial for a broader co-location context where whole scenarios are evaluated and being compared.

2.5. Chapter summary

Answers to RQ1 have been provided by drawing on findings from Paper 1 *Bonnevie et al. (2019)*. A summary was presented of how Paper 1 defines and systematically combine co-location elements into an analytical stepwise use-use interaction framework for spatial DSTs and in support of MSP. Following a recommendation stated by Paper 1, the framework was converted into a co-location framework by adding a step to balance marine use interests with environmental/nature protection. It was illustrated how Paper 1 uses the deduced stepwise framework to find limitations and strengths of the abilities of existing spatial DST-related approaches to assess co-location within MSP and how the limitations result in three co-location related recommendations for future spatial DSTs. In addition, the examined existing spatial DST approaches were briefly analysed for their ability to balance marine use interests with environmental protection including an introduction of the CIA approach. Furthermore, it was visualised how the co-location framework contains resemblances to and differences with Hägerstrand's *Time Geography* concept (1970), how MSP needs to consider non-spatial co-location drivers and barriers outside the framework as discussed in more detail in Paper 1, and how the framework indirectly supports but does not guarantee distributional aspects of fairness.

Chapter 3.
Developing and demonstrating SEANERGY

A pathway towards beginning to meet the deduced co-location-related spatial DST recommendations, is to design and develop a new spatial DST for co-location. Such a spatial co-location DST should at the same time aim to consider the general spatial DST requirements of user ease, tool accessibility, and transparency (RQ2). This chapter presents an ArcMap-based Python toolbox called SEANERGY, which has been implemented with these aims in mind, drawing to a high degree on Paper 2 *Bonnevie et al. (2020a)*, available in Appendix E, and to a smaller degree on Paper 3 *Bonnevie et al. (2020b)*, available in Appendix F. Two additional implementations of parts of the SEANERGY approach are also introduced in this chapter: an implementation into the MYTILUS tool to combine it with the environmental cumulative impact assessment (CIA) approach as described in Paper 4 *Hansen & Bonnevie (2020)*, available in Appendix G, and an implementation in a Google Drive environment to enable a stakeholder testing session, the latter not yet described in a paper but presented to some degree in Eliasen et al. (2020).

3.1. The inspiration to the SEANERGY approach

As mentioned in Paper 2, the inspiration to develop the methodology behind the spatial DST SEANERGY is threefold. Firstly, the limitations behind existing spatial DSTs to assess use-use interactions to find options for co-location deduced in Paper 1 illustrate the existence of co-location gaps for new spatial DSTs to fill out. Secondly, an increasing focus on strengthening synergies and minimising conflicts between marine uses has increased the availability of European use-use interaction knowledge that could advantageously be approached spatially. Thirdly, the existing environmental cumulative impact assessment (CIA) methodology contains options to study use-environment interactions, and it has provided methodological inspiration for developing the SEANERGY approach which is a use-use interaction approach with some resemblance to the CIA approach.

3.2. Methods to implement SEANERGY versions

Methods behind two of the three SEANERGY versions will be presented here since they were implemented by this author. The MYTILUS version is left out of this presentation of methods, since it was not implemented by this author, but resulted from collaborating with the MYTILUS developer.

3.2.1. Methods behind the main SEANERGY version

The main SEANERGY implementation builds on data gathering and processing, a programming setup, and a Baltic Sea proof-of-concept GIS analysis.

3.2.1.1. Gathering and processing pan-Baltic Sea data

The SEANERGY approach requires two types of data: data on conflict-synergy knowledge as well as spatial GIS data.

The first type of SEANERGY-required data input is place-specific conflict-synergy knowledge, enabling expert-based conflict-synergy scores. Paper 2 presents a Baltic Sea conflict-synergy matrix that has been produced in this research. As Paper 2 explains in more detail, the matrix has been produced by synthesising Baltic Sea conflict-synergy knowledge together, touching on spatial compatibility, spatial-temporal overlaps, conflict counts, synergy counts, and multi-use potentials from international MSP projects (including the EU MUSES project, Baltic SCOPE, the PartiSEApate project, Plan Bothnia, and the EU-financed COEXIST project). In this research, each pairwise conflict-synergy entry was ranked on a preliminary scale from -3 (mostly conflicting) to 3 (mostly synergic) based on a primitive order-based ranking of the deduced conflict-synergy knowledge, due to the lack of actual expert-derived conflict-synergy scores. To close some of the pairwise knowledge gaps, conflict-synergy knowledge from outside of the Baltic Sea region was included in the matrix but was given less priority when deducing the scores. Furthermore, as Paper 2 also points out, it was decided to include MPAs in the marine use definition, thereby meeting the recommendation from Paper 1 to include environmental/nature protection interests in use-use interaction considerations.

The second type of SEANERGY-required data input is GIS data describing the location of marine uses. HELCOM's online, freely accessible data portal called HELCOM Map and Data Service contains marine use GIS data for the Baltic Sea. The HELCOM datasets typically cover single or multiple years from 2011 to 2016. The datasets thus have an older temporal origin and sometimes also coarse spatial resolution, but due to the datasets being freely available with descriptive metadata, they were deemed useful as pan-Baltic proof-of-concept data for the SEANERGY approach, as mentioned in Paper 2 and Paper 3. The HELCOM data was supplemented with mussel farm location maps from the Baltic Blue Growth project, and marine underwater parks for diving from the Nordic Blue Parks project (O'Brien et al. 2014). All datasets were preprocessed after the same raster template into 1 km^2 resolution, as

Paper 2 describes. It also describes how binary thresholds were used to define the presence of marine uses in each raster cell, allowing marine uses to be either present (value=1) or not present (value=0) in each raster cell. In addition, it includes a CIA map from HELCOM's portal, to enable analytical comparisons between SEANERGY results and the CIA approach.

3.2.1.2. Technical setup of SEANERGY

The main version of SEANERGY is implemented as an ArcMap-based Python toolbox. As Paper 2 points out, the significant advantages of the ArcMap toolbox design include its already existing user interface, intuitive for GIS users, and its built-in option for implementing user-responsive metadata for each tool in the toolbox. A significant disadvantage is that ESRI ArcMap is a commercial and license-based GIS program but having made the Python code as well as the input data behind the toolbox available on GitHub as open source, other developers are able and allowed with credit to this author to implement and improve the SEANERGY tool methodology in other spatial DSTs.

A strength of using Python is the flexibility of the programming language. Python is often referred to as a scripting language because it automates certain functionality within another program, for example a GIS program (Zandbergen 2013). The module-based structure of Python includes options to install, use, and create different site packages, and it provides the scripting language with a flexible and scalable size. The SEANERGY ArcMap-based Python toolbox setup utilises open source Python modules as well as *arcpy*, the latter a site package that comes with ArcMap's built-in Python environment.

3.2.1.3. A proof-of-concept GIS analysis

The various data inputs to SEANERGY are used to produce a pan-Baltic, proof-of-concept analysis consisting of conflict-synergy maps and graphs presented in Paper 2 and Paper 3.

3.2.2. Methods behind the Google Drive-based SEANERGY version

By assisting in the organisation of the 7th Danish workshop of the SEAPLANSPACE project targeted local authorities, NGOs, and citizens in Denmark with an interest in MSP, an opportunity to test some of the SEANERGY methodology (not the SEANERGY tool itself) among stakeholders was provided to this author at the end of the research period. The Google Drive-based SEANERGY version was developed to test stakeholder interactions in the SEAPLANSPACE workshop which took place 17th of August 2020 at Aalborg University, Copenhagen. During the workshop, group discussions were organised where two groups of participants were setup to discuss expected environmental and socio-economic benefits/impacts and their spatial and user-related distributions, if new offshore fish farm sites (group 1) and new offshore wind farm sites (group 2), respectively, were introduced in a specific marine case study area Southeast of the Danish island Møn, where real businesses have shown an interest in introducing new sites of these two marine uses. More details on the workshop content is presented in Appendix A.

3.2.2.1. Preparing case-specific data for workshop

To adjust the testing of parts of the SEANERGY methodology to the specific SEAPLANSPACE case study, the required conflict-synergy score inputs and marine use GIS data inputs were selected to match the specific Danish case study in focus.

Since the workshop case study was about offshore fish farms (group 1) and offshore wind farms (group 2), respectively, only pairwise conflict-synergy knowledge related to these two marine uses was included from the SEANERGY Baltic Sea matrix, separated into a fish farm Google sheet version and a wind energy Google sheet version. To experiment with different sub-types of user-requested conflict-synergy inputs, options to provide more detailed conflict-synergy inputs than the knowledge contained in the SEANERGY matrix were provided. Appendix B describes what types of conflict-synergy knowledge inputs that were possible for the participants to explore and change.

To make up the SEANERGY-required marine use GIS inputs, case-relevant, Danish marine use GIS layers were gathered and preprocessed before the workshop. The data sources and their preprocessing are described in Appendix C. The preprocessed data was presented to the participants in different ways in group discussion part 1 and part 2. In group discussion part 1, the data was presented as a mix of vector and raster data in Baltic Explorer which is a device-flexible, free, and online GIS environment (Rönneberg et al. 2019), and it enabled options to iteratively explore marine use locations by clicking them on/off to facilitate the discussion among workshop participants on benefits, synergies, and conflicts. In group discussion part 2, the case-relevant GIS data were used to produce outputs based on the SEANERGY approach that were presented to the participants in an online Google Colab notebook and as printed maps. As described in more detail in Appendix C, the SEANERGY-relevant preprocessing differed somewhat from the preprocessing of the pan-Baltic marine use GIS data applied in the SEANERGY main version. For example, a continuous scale from 0 to 1 was applied, unlike the binary thresholds applied in the pan-Baltic proof-of-concept case study, and all marine use GIS inputs were converted to non-spatial Google sheets to be contained in the Google Drive setup.

3.2.2.2. Technical setup of the Google Drive-based SEANERGY version

The reason for the decision to implement the SEANERGY methodology testing in a Google Drive environment was to create a much faster Python environment than the SEANERGY tool itself, to enable fast Python calculations *in situ/during* and not just in preparation for a workshop setting. The Google Drive setup is created as a password-protected Google account with the sole purpose of testing the methodology of the SEANERGY approach. The Google Drive makes use of Google Colab notebooks (an online Jupyter notebook format) to contain and run the Python code online and present final maps and graphs online. The Google Colab notebooks are setup to call the previously presented data inputs contained in the Google sheets, make the SEANERGY-based analyses, and output relevant conflict-synergy related graphs and maps such as the ones presented later in this chapter. As Figure 10 illustrates, the Python code within the Google Colab documents are hidden from view as default to provide the workshop facilitator with a clear, simple overview over the few code running tasks without requiring him/her, and the observing workshop participants, to get lost in technical coding details. Instead, the facilitator and observing workshop participants can focus on the outputted SEANERGY-based graphs and maps.

The Python code in Figure 10 is divided into three parts. After first running all three parts, only the third part needs to be re-run to update SEANERGY maps and graphs if the existing conflict-synergy inputs are changed.

Neither the Google sheet data nor the Python code in the Google Colab notebooks have yet been published on GitHub. The main reason is that the code and data are more specific, context-dependent, and case-specific versions of the already published SEANERGY code and data and thus redundant to publish, and it would require much work to create proper metadata. Another reason is that much of the case-specific marine use data is not public data, which gives a reason why we are not allowed to publish it.

3.2.2.3. Stakeholder workshop with feedback

Despite the COVID-19 pandemic, seven participants physically participated in the group discussions, making up a mix of environmental protection NGO representatives and citizens/consultants with an interest in MSP. Four participated in group 1 (offshore fish farms) and three participated in group 2 (offshore wind farms).

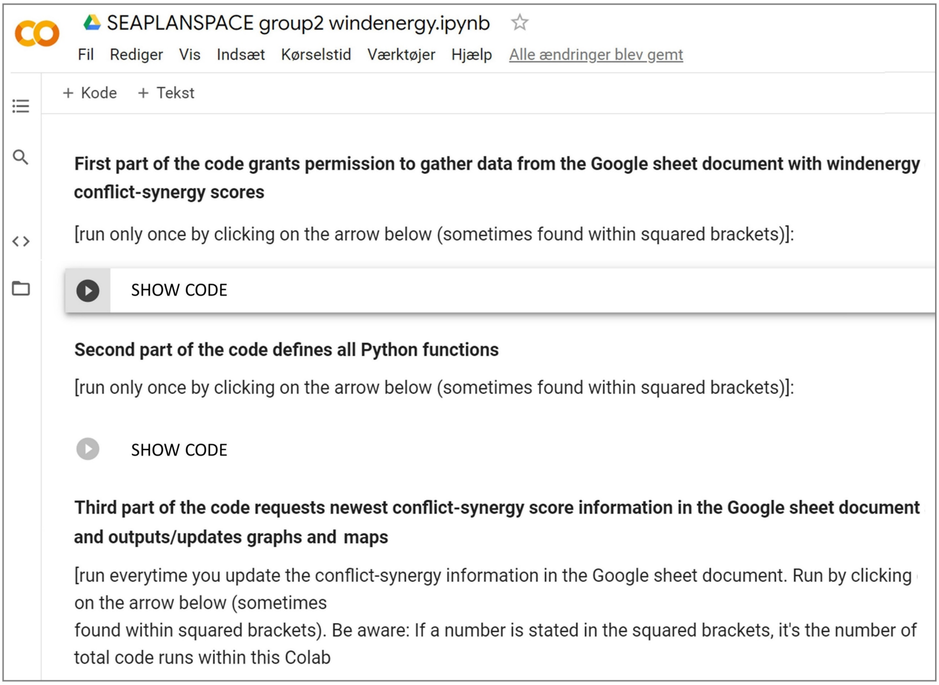

Figure 10. The Google Colab interface of the Google Drive SEANERGY version. The three Python code parts are hidden from view. The metadata descriptions were in Danish during the workshop.

Each group discussion was divided into two parts. Part 1 was on use-derived benefits and impacts assisted by the facilitator clicking case-specific marine use layers on and off in Baltic Explorer, leading to part 2 where the SEANERGY methodology was tested. During part 2, the participants were asked to focus on one perceived use-use conflict and/or one perceived use-use synergy of own choice that they had been discussing during workshop part 1 with regards to offshore fish farms (group 1) or offshore wind farms (group 2). The participants were asked to explore conflict-synergy maps and conflict-synergy graphs produced beforehand with the Google Drive setup and then try to update the input score for the chosen use-use conflict and use-use synergy to see how the change in score would cause changes in the conflict-synergy maps and graphs.

After the group discussions, the workshop ended with the participants being asked to evaluate in a questionnaire whether they found such a conflict-synergy scoring approach useful for cross-sectoral knowledge sharing in MSP.

3.3. Results part 1: A functional side of the SEANERGY approach

Results regarding the tool implementations related to the employed mathematical formulas and their technical characteristics.

3.3.1. Presenting the main implementation: SEANERGY

The mathematical foundation and tool practicalities of the spatial DST SEANERGY is presented in the following, based on Paper 2.

3.3.1.1. Formulas for conflict-synergy calculations

SEANERGY provides a novel spatial-temporal approach to use-use conflicts and synergies, summed up in four mathematical formulas with formula 1 being the main formula, all of which is presented in Paper 2. The main formula has a high resemblance to formula F.*CIA* presented in Section 2.3.2, the CIA approach by Halpern et al. (2008). However, instead of evaluating impacts from pressures on ecosystem components, SEANERGY evaluates the cumulative pairwise synergies and/or conflicts between marine uses through using expert-derived, pairwise use-use conflict-synergy scores.

SEANERGY's main formula F1.A which produces a total conflict-synergy score map is as follows:

$$S_{x,y} = \sum_{u_1=1}^{n-1} \sum_{u_2=u_1+1}^{n} U_{u_1,x,y} \cdot U_{u_2,x,y} \cdot s_{u_1,u_2} \qquad [\mathrm{F1}.A]$$

The total conflict-synergy score raster $S_{x,y}$ is the sum of all pairwise marine use score combinations for each raster cell indexed by x and y coordinates. The rasters U_{u_1}, and U_{u_2} each describe the presence of a distinct marine use, denoted u_1 and u_2, respectively. The values for the two marine uses are defined on the same scale, for example a binary or continuous scale from 0 (no presence) to 1 (full presence). In the first and current SEANERGY version, a binary scale is used. Each pairwise score combination is the multiplication of the raster cell of the first use $U_{u_1,x,y}$ and the raster cell of the second use $U_{u_2,x,y}$ and the conflict-synergy-score s_{u_1,u_2} belonging to that pairwise combination of uses. The two sum signs range over all the unordered, unique, and unidentical pairwise score combinations. A presumption behind formula F1.A is that all marine uses already have been assigned one or more geographic locations, for which reason the formula can be applied to find total conflict-synergy score patterns for existing status quo scenarios or for future, planned/imagined scenarios, as shown in Paper 2.

As Paper 2 also presents, if one instead wants to find total synergy potentials for a new, not yet located marine use u_a, formula F2.*A* can be deduced by adjusting formula F1.*A*:

$$\hat{S}_{a,x,y} = \begin{cases} \left(\sum_{u_1=1,\, u_1 \neq u_a}^{n} U_{u_1,x,y} \cdot s_{\text{pos},u_1,u_a} \right), \text{if} \left(\sum_{u_1=1,\, u_1 \neq u_a}^{n} U_{u_1,x,y} \cdot s_{\text{neg},u_1,u_a} \right) = 0 \\ -1, \text{if} \left(\sum_{u_1=1,\, u_1 \neq u_a}^{n} U_{u_1,x,y} \cdot s_{\text{neg},u_1,u_a} \right) < 0 \end{cases} \quad [\text{F2}.A]$$

In formula F2.*A*, the conflict-synergy-score matrix s_{u_1,u_2} from F1.*A* has been changed to s_{u_1,u_a} and divided into two different matrices: one with only positive scores s_{pos,u_1,u_a} and another with only negative scores s_{neg,u_1,u_a}, where the lack of a pairwise positive/negative score, respectively, will be represented by a zero. By assuming that a new specific marine use u_a in theory could be located in all locations where existing marine uses take place (in practice, its location will be limited by technical and operational space requirements), its synergy score potential $\hat{S}_{a,x,y}$ is defined to be for each raster cell the sum of each marine use u_1 present in that raster experiencing a positive score with the chosen new, specific marine use u_a multiplied with the positive conflict-synergy score s_{pos,u_1,u_a}. To only consider the synergies that do not overlap conflicts, all raster cells where negative scores for the chosen new, marine use s_{neg,u_1,u_a} are present are overruled with the value of -1. The total synergy potential map $\hat{S}_{a,x,y}$ is thus made up by a) no-go areas with the value of -1 for all raster cells that contain at least one negative pairwise score for the new marine use, and b) synergy potential areas with a total positive score sum for the raster cells where no negative pairwise scores for the new marine use are present.

As shown in the Appendix of Paper 2, alternative, specific versions of formulas F1.*A* and F2.*A* can be deduced, if one decides to count instead of weighting synergies and/or conflicts, when a certain condition is met. The alternative version of F1.*A* is:

$$S_{con,x,y} = \sum_{u_1=1}^{n-1} \sum_{u_2=u_1+1}^{n} U_{u_1,x,y} \cdot U_{u_2,x,y} \cdot s_{con=1,u_1,u_2} \quad [\text{F1}.B]$$

In F1.*B*, the score $s_{\text{con}=1,u_1,u_2}$ is defined to be a binary case of either 1 (if a condition con is met) or 0 (if the condition is not met). Thus, the resulting map $S_{con,x,y}$ counts all instances of a certain condition for each raster cell where marine uses already have been given a location. Interesting specific conditions (con) to count could be:

a All pairwise use combinations.
b Pairwise use combinations that have a positive and/or negative conflict-synergy score attached.
c Pairwise use combinations that belong to a specific conflict-synergy category.
d All pairwise use combinations – or only the combinations with a conflict-synergy score – that include a specific marine use.
e Pairwise use combinations that are mobile.
f Pairwise use combinations with an overlap in spatial vertical location.
g Pairwise use combinations with different spatial vertical locations.
h Pairwise use combinations that could be part of a multi-use constellation according to the MUSES project.

Thus, F1.*B* does not only include conflict-synergy score inputs but also other types of conflict-synergy attribute inputs depending on the chosen condition (con).

F2.*B* considers a binary case of F2.*A*, similarly to how F1.*B* considers a binary case of F1.*A*:

$$\hat{S}_{\text{pos}=1,x,y} = \begin{cases} \left(\sum_{u_1=1,\, u_1 \neq u_a}^{n} U_{u_1,x,y} \cdot s_{\text{pos}=1,u_1,u_a} \right), \text{if } \left(\sum_{u_1=1,\, u_1 \neq u_a}^{n} U_{u_1,x,y} \cdot s_{\text{neg},u_1,u_a} \right) = 0 \\ -1, \text{if } \left(\sum_{u_1=1,\, u_1 \neq u_a}^{n} U_{u_1,x,y} \cdot s_{\text{neg},u_1,u_a} \right) < 0 \end{cases} \qquad [\text{F2}.B]$$

In F2.*B*, each synergy score $s_{\text{pos}=1,u_1,u_a}$ is always 1 in order to count the number of potential synergies instead of weighting their synergy size.

F1.*A*, F2.*A*, F1.*B*, and F2.*B* – the four formulas presented in Paper 2 – are thus all different derivations of the same initial formula where the different formulas vary according to whether they only focus on already located marine uses (F1.*A* and F1.*B*) or also include a new, not yet located marine use (F2.*A* and F2.*B*), and to whether they are based on weighting scores (F1.*A* and F2.*A*) or on conditional counts (F1.*B* and F2.*B*).

3.3.1.2. Tools in SEANERGY

Each of the four mathematical formulas has been dedicated its own tool within the SEANERGY toolbox. Besides the four formula-based spatial tools, the SEANERGY toolbox consists of two further tools: a spatial Monte Carlo uncertainty tool and a non-spatial tool to browse specific pairwise conflict-synergy matrix content. All six tools are shortly presented in Paper 2.

Tool 1: Calculate Score Map. This tool implements formula F1.*A* to calculate total synergy-and/or-conflict score raster maps for already located marine uses in status quo or in an imagined/future scenario. The tool allows some user flexibility by enabling the user to move away from the default setting of exploring all marine use combinations to only explore the subset of marine use combinations where a fixed, marine use is included, exploring where and to which degree, for example, fish farms experience potential synergies and conflicts with all other marine uses. Furthermore, the user is faced with options to output 1-3 statistical tables.

Figure 11 illustrates the ArcMap-based map interface with the SEANERGY toolbox menu and a conflict-synergy map output. Overall synergies are defined to be total potential synergy sums larger than conflict sums (positive scores), and overall conflicts are defined to be total potential conflict sums larger than synergy sums (negative scores).

Figure 12 illustrates the interface of the *Calculate Score Map* tool. The descriptive metadata in the right interface side changes to match the requested specific input, as the user clicks around.

Tool 2: Find Synergy Potential Scores for a New Marine Use. This tool implements formula F2.*A* to calculate total potential synergy scores for a new, not yet located, specific marine use, for example, diving, as presented in Paper 2. The tool does not consider location suitability criteria for the specific marine use in focus, as mentioned in Paper 3. Therefore, use-specific technical and operation space requirements such as the ones explored in van den Burg et al. (2019) will have to be deduced outside of SEANERGY to determine whether areas with SEANERGY synergy potentials and no expected conflicts are suitable for the specific use in practice.

Tool 3: Calculate Count Map. This tool implements formula F1.*B* to calculate total synergy-and/or-conflict count raster maps for already located marine uses in status quo or in an imagined/future scenario, as presented in Paper 2. Like the tool *Calculate Score Map*, it allows the user to focus on one specific marine use and its pairwise combinations with other marine uses. It implements the count choices listed in Section 3.3.1.1 which reveals through count choice *a* to *h* that its conflict-synergy knowledge inputs are not always scores.

Tool 4: Find Synergy Potential Counts for a New Marine Use. This tool implements formula F2.*B* to count total synergy potentials for a new, not yet located, specific marine use, as explained in Paper 2. Like the tool *Find Synergy Potential Scores for a New Marine Use*, it does not consider location suitability criteria for the specific marine use in focus, as mentioned in Paper 3.

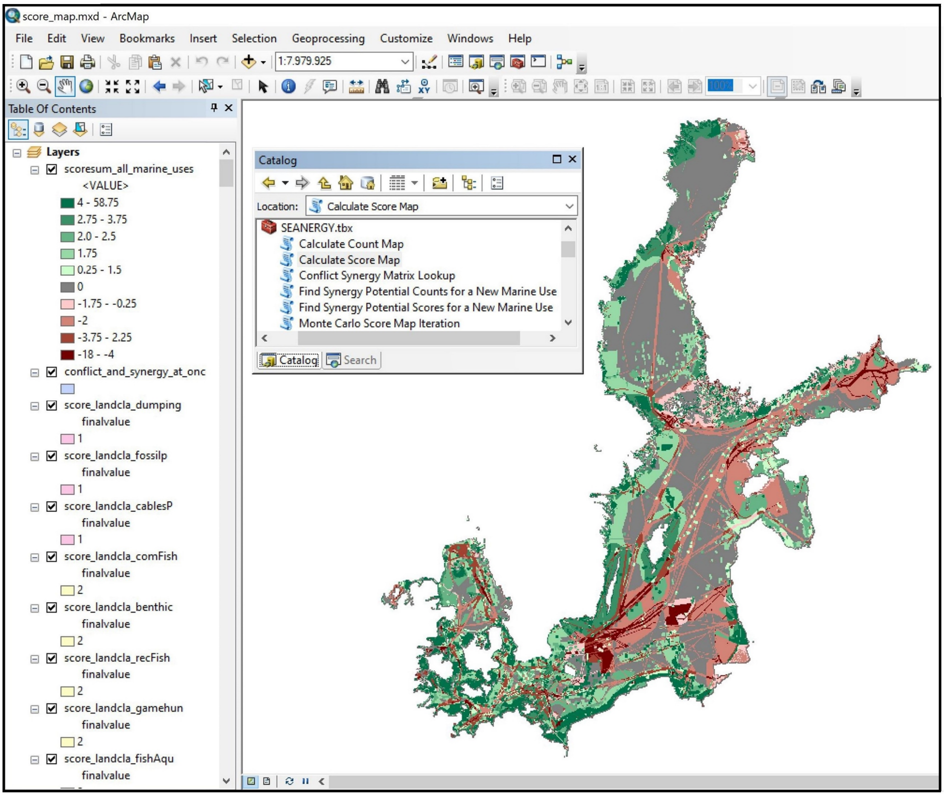

Figure 11. The ArcMap-based interface of SEANERGY. The green areas contain overall synergies (positive scores) separated into classes with a quantile distribution. The red areas contain overall conflicts (negative scores) separated into classes with a quantile distribution. The grey areas contain negative conflict sums and positive synergy sums of equal size.

Tool 5: Monte Carlo Score Map Iteration. Uncertainty analyses are useful to explore the sensitivity or robustness of model outputs to specific input uncertainties, and iterative Monte Carlo simulation is a very common uncertainty analysis technique (Lilburne and Tarantola 2009). As explained in Paper 2, SEANERGY implements a Monte Carlo-based uncertainty analysis tool called *Monte Carlo Score Map Iteration* to explore where the overall sum output map of the tool *Calculate Score Map* is sensitive to specific score input uncertainties. Sensitivity in the specific uncertainty test is defined to be for each raster cell when the majority of all Monte Carlo runs with test-specific randomised input changes return a different positive/neutral/negative sign than the corresponding raster cell of the baseline map which is the total conflict-synergy map without input changes, corresponding to the total conflict-synergy map result of tool 1.

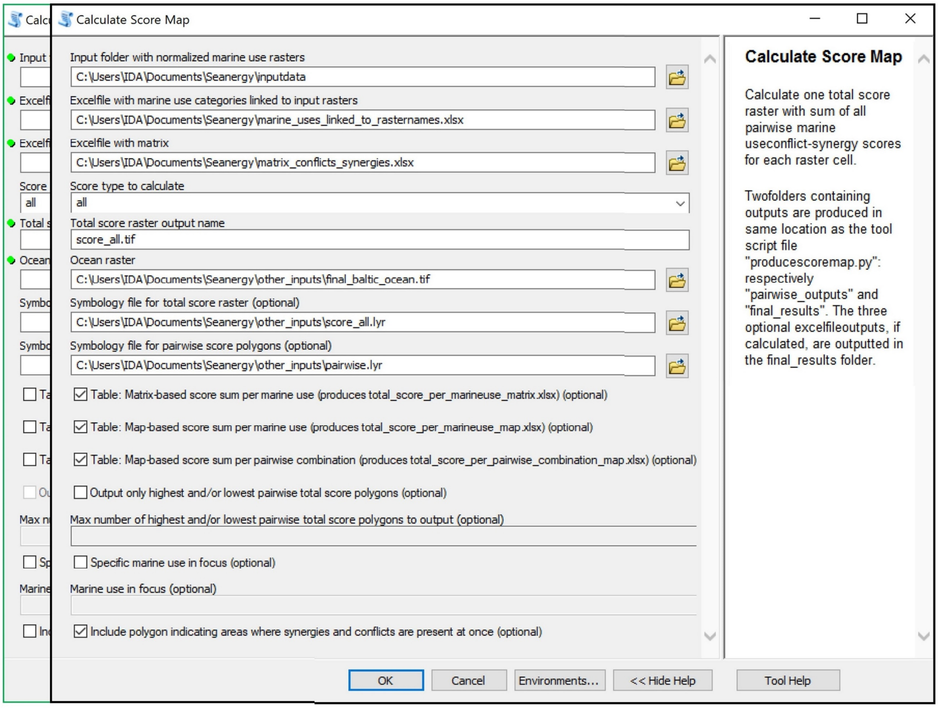

Figure 12. The interface of the Calculate Score Map tool. It is shown with suggested input examples, the inputs enabling the tool to run by pressing OK. The green frame illustrates the default interface before filling in inputs. Mandatory inputs are marked with green dots.

As Paper 2 explains, three different uncertainty tests are implemented, based on the presumption of a ranking scale from -3 to 3 containing steps of 1. The first uncertainty test (test 1) allows the score inputs to randomly and iteratively change in each Monte Carlo run, with a maximum step of -1 or +1 to mirror the uncertainty case that experts could be in doubt about which of two neighbouring conflict-synergy categories that a pairwise combination belongs to. The second uncertainty test (test 2) questions the ranking scale by allowing all input scores that are neither the minimum score of -3 nor the maximum score of +3 to be a random ratio of the score of the more extreme neighbouring score category. The third uncertainty test (test 3) combines both test conditions.

Tool 6: Conflict Synergy Matrix Lookup. As a sixth tool introduced in Paper 2, SEANERGY implements its only non-spatial tool: This matrix lookup tool to lookup user-requested specific pairwise matrix content to increase transparency of the score knowledge behind the conflict-synergy maps produced by the spatial tools.

3.3.1.3. A stepwise guide to using SEANERGY

A stepwise process of how to use SEANERGY, where in the process its six tools can be applied, and who the intended users are is described in Paper 2 and visually reproduced in Figure 13. The various tools and various tool user choices support iterative processing rounds (maybe even preprocessing rounds if new GIS data is introduced) to update and explore map changes based on user feedback. As Paper 2 states, running time of tools typically spans from 20 seconds to 14 minutes depending on the parameter settings, except the uncertainty tool which takes approximately 1 hour to run for 100 iterations, making in particularly this latter tool currently unfit for *in situ* iterative stakeholder explorations. As Figure 13 shows, the intended stakeholders to use SEANERGY are many though it requires facilitation by a GIS expert in collaboration with MSP planners.

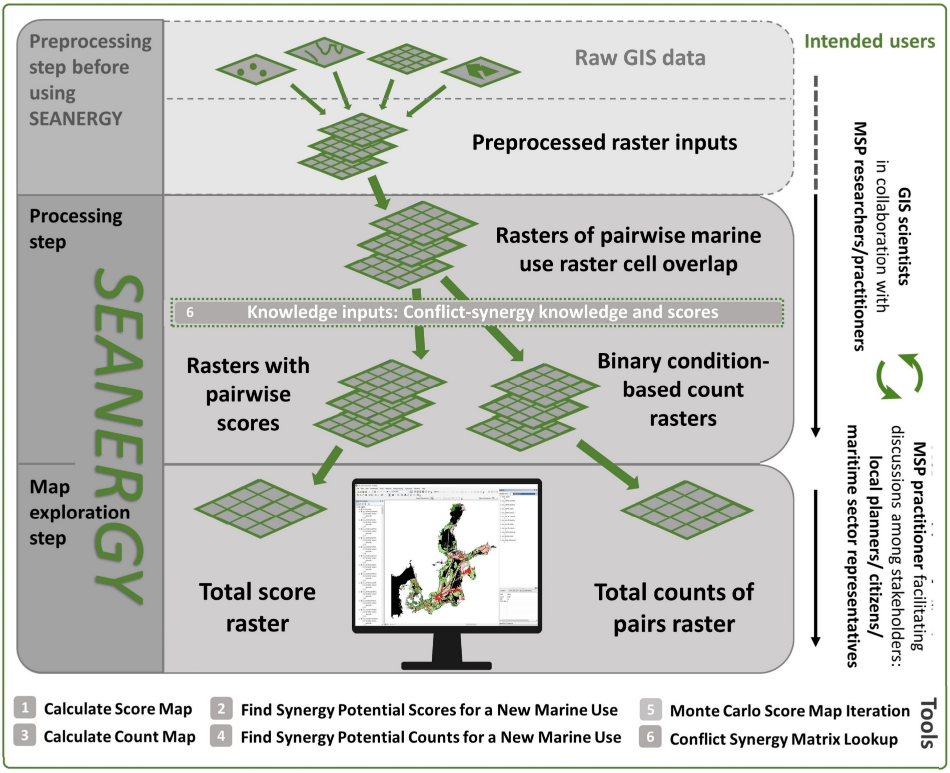

Figure 13. Stepwise model of SEANERGY linked to tools and intended users. This figure is created by this author, printed in Eliasen et al. (2020), and it is an alternative version of Figure 1 of Paper 2: Bonnevie et al. (2020a).

3.3.2. A technical SEANERGY-CIA combination in MYTILUS

Paper 4 presents the main SEANERGY approach (formula F1.*A*) in combination with the CIA-based approach (formula F.*CIA*) in the MYTILUS tool, enabling options for the user to visually compare maps based on the two approaches within the same tool, and enabling very fast calculations (Hansen 2019). Figure 14 presents the overall decision flow for users within the MYTILUS tool for the combined approach. As described in *Hansen & Bonnevie 2020*, the combination allows the user to identify areas with; a) high environmental impact and high conflict, b) high environmental impact and synergy, c) low environmental impact and high conflict, and d) high environmental impact and synergy.

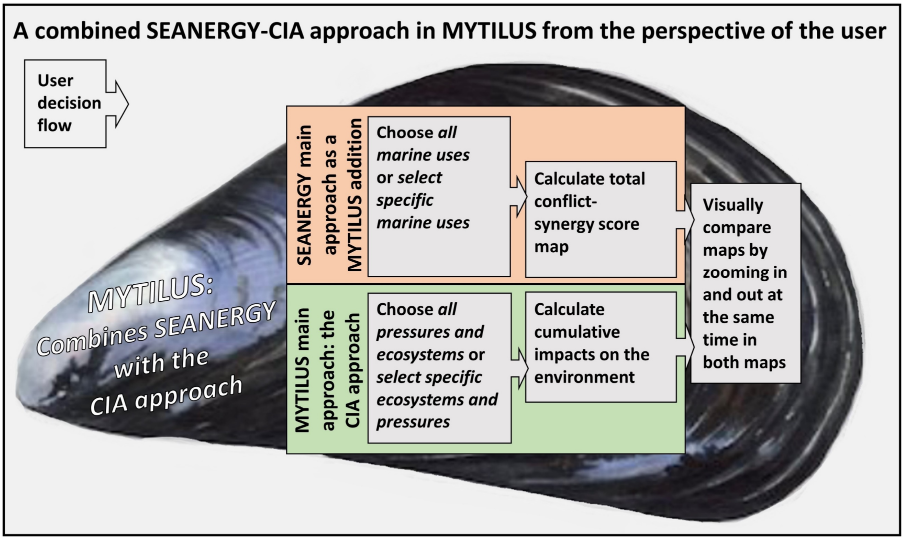

Figure 14. User decision flow within a combined SEANERGY-MYTILUS. The main part of SEANERGY (formula F1.A) is combined with the CIA approach (formula F.CIA) in MYTILUS.

3.3.3. A Google Drive implementation with new SEANERGY experiments

The Google Drive version works similarly to MYTILUS with the main SEANERGY approach (formula F1.*A*) but focuses on one marine use, either offshore fish farms (group 1) or offshore wind farms (group 2), and its pairwise conflict-synergy scores with other marine uses.

Besides improving the SEANERGY-based outputs with automatically generated graphs, the Google Drive implementation extends the SEANERGY approach with conflict-synergy calculations across neighbouring raster cells. Approaching spatial conflict-synergy locations from the practical point of view of a person observing a 2D map, one can divide potential conflict-synergy occurrences into *overlap* *conflicts/synergies* that operate for marine uses being present in the same raster cell, and *neighbour conflicts/synergies* operating for marine uses in different raster cells but within a certain horizontal proximity to each other that spans multiple raster cells. The SEANERGY toolbox does not distinguish between these two definitions. It uses F1.A to calculate a mix of *overlap synergies/conflicts* and *neighbour synergies/conflicts* within single raster cells, since the Baltic Sea conflict-synergy knowledge does not contain any knowledge on reach distance zones for neighbour synergies/conflicts. As the Google Drive implementation presents user-editable reach distances for *neighbour synergies/conflicts* that the group work participants were free to update, the Google Drive implementation was able to calculate the *neighbour synergies/conflicts* with another formula than F1.A and sum it to the *overlap synergies/conflicts* calculated with F1.A:

$$S_{u_l,x,y} = S_{O,u_l,x,y} + S_{N,u_l,x,y} \qquad [\mathrm{F1}.C]$$

In F1.C , the final conflict-synergy score $S_{u_l,x,y}$ for a specific, already located marine use u_l is the sum of a) the overlap conflict-synergy score sum $S_{O,u_l,x,y}$ calculated with the u_l-specific instance of F1.A and b) the u_l-specific neighbour conflict-synergy score sum $S_{N,u_l,x,y}$ calculated with the following, not yet peer-reviewed formula:

$$S_{N,u_l,x,y} = \left(\sum_{u=1,u\neq u_l}^{n} U_{u,x,y} \cdot s_{u,u_l} \right) \cdot M_{Z,x,y} \cdot M_{\sim u_l,x,y} \qquad [\mathrm{F1}.D]$$

The total neighbour conflict-synergy score $S_{N,u_l,x,y}$ for a raster indexed with x,y for the specific, already located marine use u_l is with formula F1.D the sum of all marine uses that are different from u_l multiplied with their pairwise neighbour score s_{u,u_l} with u_l. The sum is multiplied with a binary mask $M_{Z,x,y}$ dictating whether each x,y coordinate pair instance is within the pairwise reach distance zone Z surrounding the marine use u_l, and multiplied with a binary mask $M_{\sim u_l,x,y}$ dictating whether each coordinate pair x,y does not contain marine use u_l. The last requirement obstructs *neighbour synergies/conflicts* from involving marine uses existing within the same raster cell to clearly distinguish *neighbour synergies/conflicts* from *overlap synergies/conflicts* to avoid double-counting. With this method, each marine use pair is allowed two different conflict-synergy score inputs: one for *overlap synergies/conflicts* and one for *neighbour synergies/conflicts*. This distinction enables the user to consider *neighbour synergies* for marine uses that experience *overlap conflicts* if overlapping in the same raster cell. For example, wind farms can benefit nearby commercial fishers through artificial reef effects, but the two marine uses cannot overlap (Hooper et al. 2015).

The Python implementation of formula F1.*D* as applied in the SEAPLANSPACE group work 2 (offshore wind farms) is illustrated in Figure 15 with offshore wind farms making up the specific, already located marine use u_l.

Key Python calculations to implement considerations of **neighbour** synergies/conflicts

np for numpyarray
lf for true/false numyarrays

- **npIfMarineUseExist** is a numpyarray describing whether a specific marine use exist in each raster cell (presence > 0.).
- **npMarineUse** is a numpyarray describing the presence degree of a specific marine use on a continuous scale from 0 (not present) to 1 (most present).

```
npIfMarineUseExist = np.where(npMarineUse > 0.), True, False)
```

- **npIfMarineUseExistOutsideWindfarmarea** is a numpyarray describing whether a specific marine use exist in each raster cell located outside of windfarm raster cells.
- **npNotWindfarmarea** is a numpyarray describing where windfarms are not present.

```
npIfMarineUseExistOutsideWindfarmarea = np.where(
    npIfMarineUseExist & (
        npNotWindfarmarea == 0.), True, False)
```

- **npIfMarineUseExistAndWithinZone** is a numpyarray describing whether a specific marine use exist in each raster cell that does not contain windfarms AND is within the conflict/ synergy reach distance zone from windfarms.
- **npEuclideanDistances** is a numpyarray with Euclidean distances in metres to existing/ planned windfarms.
- **specificConflictOrSynergyReach** is a number in metres for the radius of the Euclidean distance zone in which the neighbour conflict/synergy operates.

```
npIfMarineUseExistAndWithinZone = np.where(
    npIfMarineUseExistOutsideWindfarmarea & (
        npEuclideanDistances <= specificConflictOrSynergyReach), True,
            False)
```

- **npMarineUseThatExistWithinZone** is a numpyarray with the presence degree of the specific marine use within the conflict/synergy reach distance zone.

```
npMarineUseThatExistWithinZone =
    (npIfMarineUseExistAndWithinZone*
        npMarineUse).astype('float64')
```

- **npTotalPairwiseScore** is a numpyarray where the specific input neighbour score (negative if conflict; positive if synergy) for the specific marine use pair is transferred unweighted out on all raster cells in the map inside the distance zone where only marine use 2 exist (windfarms constitutes marine use 1).
- **pairwiseScore** is the inputted pairwise score (negative if conflict; positive if synergy).

```
npTotalPairwiseScore = pairwiseScore*npMarineUseThatExistWithinZone
```

Figure 15. Key Python calculations to implement neighbour synergy/conflicts. A reach distance value decides whether the marine use is within reach of offshore wind farms for the neighbour conflict/synergy to be considered in the map.

Besides the experimental methodological updates to SEANERGY, the Google Drive environment enables a much faster Python environment than the SEANERGY tool itself, enabling Python calculations *during* and not just in preparation for a workshop setting. As Eliasen et al. (2020) write, it only *"took a few seconds"* to update the conflict-synergy maps and graphs within the Google Drive environment, when a specific pairwise marine use score was changed based on suggestions from the SEAPLANSPACE group work participants.

3.4. Results part 2: Conflict-synergy GIS analyses and feedback

Results regarding demonstrating the SEANERGY approach relate to proof-of-concept GIS analyses with map and graph outputs as well as feedback from participants in the SEAPLANSPACE workshop.

3.4.1. GIS analyses with SEANERGY for a pan-Baltic Sea

SEANERGY-based proof-of-concept GIS analyses for a pan-Baltic Sea are presented at an overall level in Paper 2 and with more detail in Paper 3. Paper 2 furthermore supplements the SEANERGY findings with CIA-results to illustrate the advantages of combining the two approaches.

3.4.1.1. Baltic Sea co-location analyses for existing and future conditions

Paper 2 presents an overall Baltic Sea proof-of-concept analysis, demonstrating how SEANERGY can support the MSP process with co-location knowledge by spatially visualising potential synergies and potential conflicts on maps for one or more already located marine uses or for a not yet located specific marine use. In the conflict-synergy score map for already located uses, Paper 2 only visualises robust conflict-synergy patterns in its overall conflict-synergy map by leaving out all sensitive raster cells that were found to be sensitive in any of the three uncertainty tests based on 100 Monte Carlo runs. It shows how tool 1 and tool 3 produce conflict-synergy sum maps and conflict-synergy count maps, respectively, for an *ex post* marine use spatial status quo distribution, methods also applicable for an *ex ante* future spatial planning scenario, while tool 2 and tool 4 *ex ante* produce potential synergy sum maps and potential synergy count maps for a not yet located specific inputted marine use, e.g. diving, respectively. Diving is used as an example due to its high apparent synergy potential in the Baltic Sea. With tool 2 and tool 4, planners can select areas for a new marine use such as diving in a manner that optimise space by increasing synergies and avoiding conflicts.

3.4.1.2. A scenario-based SEANERGY approach with the CIA approach

While paper 4 presents the technical advantages of combining the SEANERGY approach with the CIA approach into the same tool, Paper 2 demonstrates the analytical advantages of combining the two approaches through pan-Baltic maps and graphs. Paper 2 also illustrates that if MSP planners combine scenario-based SEANERGY conflict-synergy analysis results with CIA results, they can use the combined maps to select potential multi-use areas where the SEANERGY-indicated synergy potential is high and where the CIA-indicated negative environmental impacts are low. The combined maps can also be used to select areas for conflict management where the conflict potential is high and CIA-indicated negative environmental impacts are high.

3.4.1.3. A cross-sectoral SEANERGY use catalogue

Paper 3 provide details of the potentials for SEANERGY to answer specific co-location questions of relevance for MSP. It presents 8 specific conflict-synergy-related questions and shows how SEANERGY provides answers to them, constituting a cross-sectoral SEANERGY use catalogue. Each question is listed together with the specific SEANERGY tools and tool outputs that provide answers to the question. Furthermore, the questions are categorised into three different use contexts: 1) non-spatial discussions, 2) status quo and existing spatial scenarios with the sub-category of spatial-temporal attribute considerations, and 3) new spatial scenarios. The questions span knowledge concerning non-spatial conflict/synergy potentials, spatial conflict/synergy potentials overall and for specific marine uses, spatial-temporal compatibility potentials such as non-overlapping different vertical locations in the same raster cell and mobile marine uses overlapping in the same raster cell, multi-use constellation potentials, and options for considering conflict-synergy potential when locating new marine uses. Paper 3 furthermore shows how SEANERGY not only explores spatial conflict-synergy patterns but enables the user to link the conflict-synergy patterns to the marine uses producing them by: 1) allowing the user to focus on one marine use in the tool calculations, and 2) allowing the user to explore the specific marine uses and their pairwise conflict-synergy knowledge in specific raster cells through clicking around in the conflict-synergy map with the ArcMap-built-in-identify button.

3.4.2. SEAPLANSPACE workshop results

The SEAPLANSPACE workshop provided feedback on three different aspects regarding the SEANERGY methodology:

1) What is the overall impression among group discussion participants regarding listing and ranking conflicts and synergies?

Observations by the BONUS BASMATI team during the group work and written feedback from the participants gave the overall impression of *"the SEANERGY method and concept as highly relevant for identify and addressing conflicts and especially potential synergies"* (Eliasen et al. 2020). During the group work, some of the participants seemed to find it difficult to understand the calculations behind the conflict-synergy map and corresponding graphs but they were very interested in exploring them, and in exploring their potentials further. They explicitly pointed out that they found it important to work with conflicts and synergies, while some of them questioned the ability to rank conflicts and synergies in an objective or representative way (Eliasen et al. 2020). The written feedback based on 6 questionnaires filled in by the participants after finalised workshop is summed up in the following box:

Summary of written feedback (6 filled questionnaires)

The background of the 6 participants across group 1 (offshore fish farms) and group 2 (offshore wind farms) were a mix of environmental NGO representatives, consultants/journalists, and with personal and work-related MSP interests. Generally, the participants seemed to find it difficult to rank/compare different synergies and conflicts, and it was difficult for them to understand and explore all map and graph details within the limited group work time. However, all participants clearly stated that they found it very important to rank or at least explore synergies and conflicts, also from a spatial point of view. They found conflict-synergy maps and graphs relevant to highlight cross-sectoral challenges and multi-use potentials. Most of them found conflict-synergy maps and graphs to be equally important. Different participants listed different stakeholders for whom they would expect conflict-synergy visualisations to be important, including municipalities, the aquaculture sector, MSP decision-makers, and citizens in the hearing process. The variety in stakeholders listed illustrate a broad spectrum of potentially relevant stakeholders for whom conflict-synergy maps/graphs could be important.

2) Can updates to pre-inputted conflict-synergy knowledge *in situ/during* a group discussion to explore the changes on graphs and maps contribute actively to a conflict-synergy discussion?

The BONUS BASMATI team experienced a positive reaction to iteratively updating conflict-synergy maps by changing scores in the SEAPLANSPACE workshop (Eliasen et al. 2020). The calculation details of the SEANERGY approach was not explained to the participants since it was considered too technical but *overlap* *conflict/synergies* and *neighbour conflict/synergies* were presented conceptually as being conflict/synergies between marine uses in the same spot versus conflicts/synergies experienced between marine uses over certain distances, respectively. The offshore wind farm group (group 2) focused their conflict-synergy discussion on the particular *neighbour conflict* of coastal summer cottages being visually disturbed by offshore wind farms, making it relevant for the facilitator (this author) to show how the conflict-synergy map and conflict-synergy input graphs change, if the neighbour conflict reach distance zone to offshore wind farms for coastal summer cottages is changed to a much larger number and its corresponding conflict score is made worse. Figure 16 visualises how a change in neighbour conflict reach for coastal summer cottages to offshore wind farms from 3000 metres to 20000 metres as well as a change in score from -1 to -3 causes the coastal summer cottages to be included in the conflict-synergy map after the change. Figure 17 shows how the marine use input summary graphs change correspondingly. Viewing the change directly in the conflict-synergy map and input summary graphs inspired aha-moments among the participants (Eliasen et al. 2020). Thus, the update to the conflict-synergy maps and graphs during the group work enabled the participants to see the relevance of conflict-synergy maps and graphs for spatially exploring conflicts and synergies.

3) Can the exploration of marine use locations in an online visualisation platform such as Baltic Explorer support conflict-synergy discussions?

The SEAPLANSPACE workshop evaluated options to combine marine use location maps with conflict-synergy maps as highly useful for driving the conflict-synergy discussion. Options to click marine use GIS layers on and off within Baltic Explorer in the first of part of the SEAPLANSPACE group work helped focus the discussion on specific marine uses in a systematic way (Eliasen et al. 2020). The systematic clicking on and off enabled aha-moments among the group work participants, for example, the comment "*so many cables?*" to the cable/pipeline GIS layer and requests for other, not-included data layers found to be relevant for potential conflicts/synergies, for example, bird migration routes and marine water currents (Eliasen et al. 2020). Furthermore, the second part of the SEAPLANSPACE group work that focused on the conflict-synergy maps and -graphs supplemented the conflict-synergy visualisations with physically printed thematic marine use location maps that were given much attention. Especially the culture and recreation location map for the offshore wind farm group (group 2) presented in Figure 18 supplemented the conflict-synergy discussion in group 2 through its ability to highlight locations of less economic marine uses that might conflict with wind farms. However, the participants explicitly stated clear preferences for the flexible clicking on/off options in Baltic Explorer compared with a printed, static map in when many marine uses overlap.

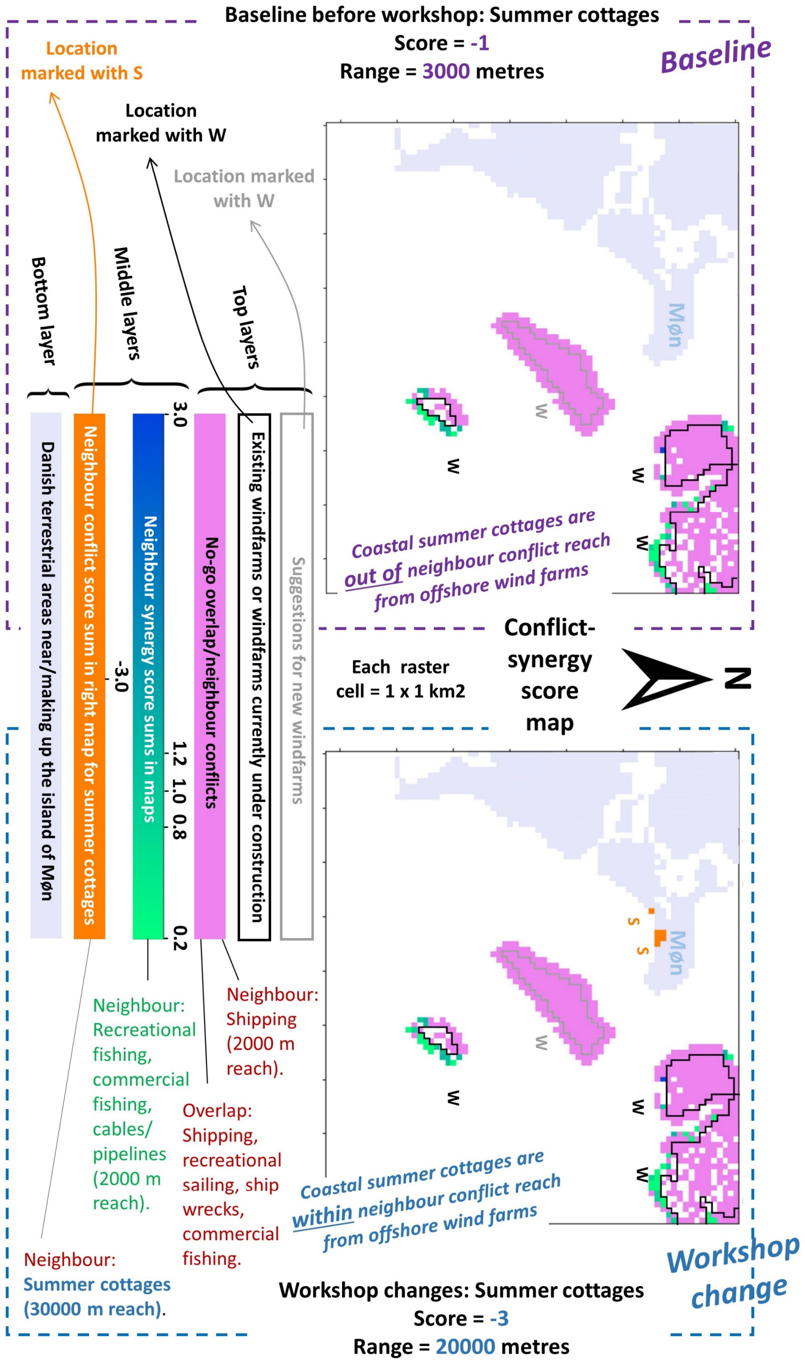

Figure 16. Map-illustrated change turning coastal summer cottages into a conflict. The coastal summer cottages turn conflicting with offshore wind farms if the conflict reach distance is changed from 3 km (baseline in left map) to 20 km (new scenario in right map).

Figure 17. Graph-illustrated change in conflict inputs for coastal summer cottages. The conflict reach distance was changed from 3 km (baseline in left map) to 20 km (new scenario in right map) and the input score was changed from -1 to -3.

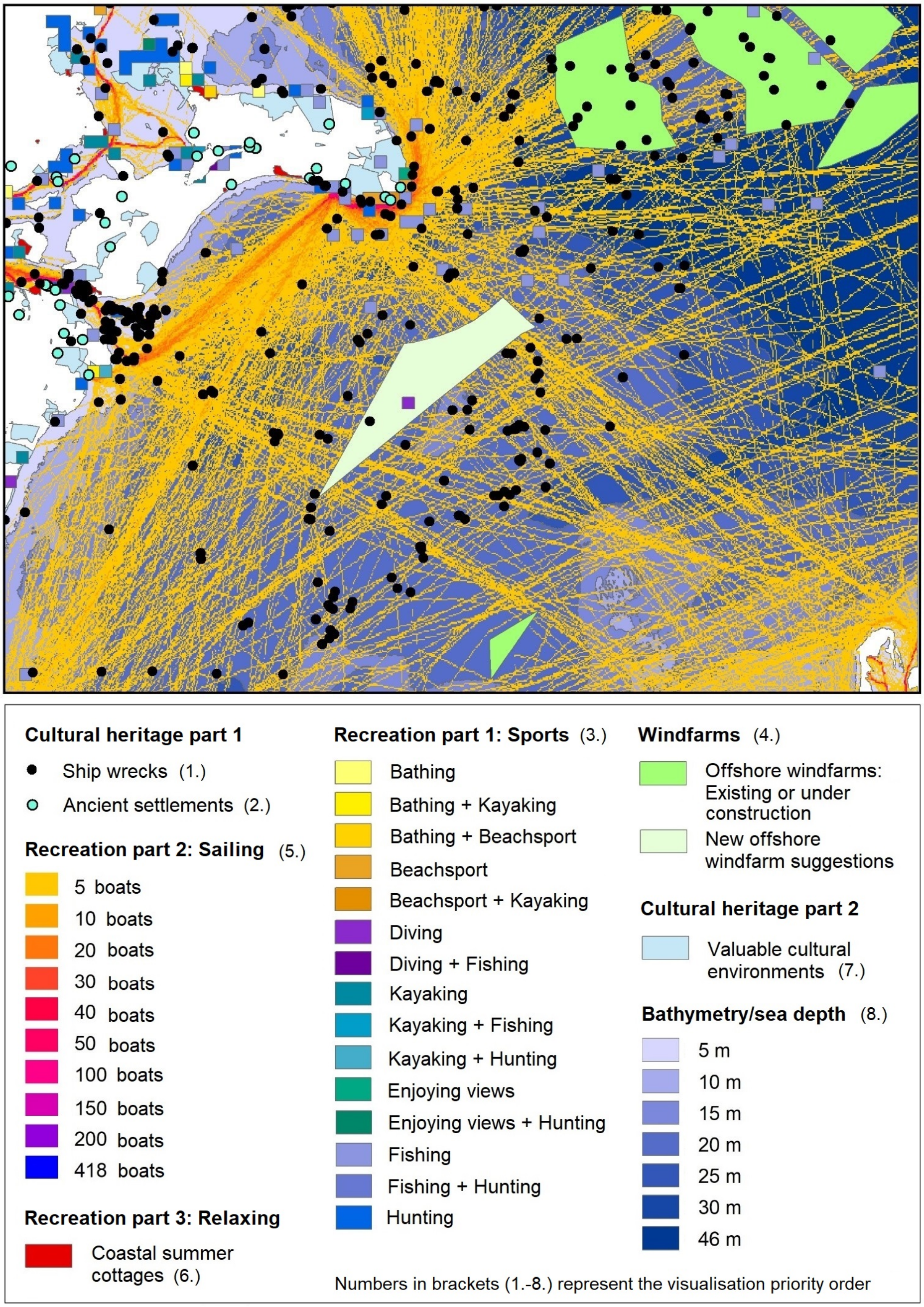

Figure 18. Marine use location map focusing on culture and recreation. It was printed as a supplement to conflict-synergy visualisations in the SEAPLANSPACE workshop.

3.5. A SEANERGY-based discussion on co-location and functional abilities

By drawing on SEANERGY knowledge presented in Paper 2 and Paper 3 and linking it to the stepwise co-location framework of Paper 1, it will be discussed to what degree the SEANERGY approach considers co-location. Secondly, it will be evaluated to which extent the SEANERGY approach ensures user ease, tool accessibility, and transparency.

3.5.1. Co-location abilities

The logic of the SEANERGY approach has significant resemblance to the stepwise co-location framework presented in Paper 1 in its treatment of co-location knowledge in all three SEANERGY versions, as will be demonstrated, though small variations exist between the different versions.

Firstly, SEANERGY methodology spatially-temporally locates use-use interactions (step 1 of the stepwise framework). With the SEANERGY methodology, it becomes possible to apply a spatial angle to a traditionally non-spatial matrix-based approach to use-use interactions, as Paper 2 points out. As has been shown, the main SEANERGY approach (formula F1.*A*) locates use-use interactions by locating raster cells where more than one interacting marine use exist. The Google Drive version expands the location of marine use-use interactions to also involve use-use interactions not just within raster cells but also across raster cells within a horizontal conflict-synergy reach distance specified for individual marine use pairs. All three SEANERGY versions thus spatially-temporally locates use-use interactions (step 1 of the stepwise framework). By referring to the pairwise use-use functional setup within the SEANERGY matrix, one can argue that the use-use interaction detail level within the SEANERGY approach stays at an overall pairwise level (sub-level 1 of step 1) instead of diving into multiple conflict-synergy examples based on multiple spatial-temporal links (sub-level 2 of step 1). The Google Drive version sub-divides this overall use-use categorisation into sub-categories of *overlap synergy/conflict* and *neighbour synergy/conflict*. None of the SEANERGY implementations are so detailed that they focus on spatial-temporal links in their functional setup. However, by referring to the conflict-synergy content instead of the functional matrix setup, one can argue that SEANERGY approach does delve into the details of spatial-temporal links (sub-level 2 of step 1) when such knowledge exists. In all its implementations, the SEANERGY approach explicitly considers specific cases of positive/negative spatial-temporal links by listing them as conflict-synergy attributes to the interacting marine use pairs when such knowledge is found to exist (in the MYTILUS implementation, all text-based descriptions are left out but its baseline scores are the same as in the SEANERGY toolbox and are thus still based on spatial-temporal link information). For example, the inclusion in the SEANERGY matrix of multi-use potentials from the EU MUSES project (Depellegrin et al. 2019; Schultz-Zehden et al. 2018) introduces considerations of both location links, technical links, environmental links, and user attraction links. For example, the combination of recreational fishing, boating, and cultural heritage (UNESCO sites) that is presented as a specific example of marine uses with multi-use potentials in Paper 3 involves the sharing of users in various activities such as fishing and cultural heritage practices (user attraction link) in the same area (location link). It furthermore involves the sharing of gear, for example, the sharing of boats (technical link), and if shipwrecks are present at the cultural heritage site, it can cause artificial reef effects attracting fishes of interest for fishing (environmental link). Even though the MUSES knowledge enables location link considerations to a certain degree, the full scale of location links concerning vertical, horizontal, and temporal considerations are more thoroughly and systematically included into the SEANERGY matrix through the inclusion of spatial-temporal marine use attribute knowledge from the EU-financed COEXIST project (2013) which enables SEANERGY to locate areas containing spatial compatible marine uses located in different vertical marine locations, with cables/pipelines and shipping used as an example in Paper 3. By including such spatial-temporal marine use attribute information, the SEANERGY approach follows the first of the three spatial DST-related co-location recommendations in Paper 1: an urge to explore spatial-temporal links to find sources for potential conflicts and synergies.

Secondly, the SEANERGY approach informs whether a specific marine use pair implies a synergic or conflicting character (step 2 of the stepwise framework). As described in Paper 2, SEANERGY derives a conflict-synergy score based on, for example, the number of conflicts and synergies listed in the partiSEApate project (Ruskule et al. 2014). Paper 2 points out how SEANERGY expands the matrix-based tradition of only including simple spatial compatibility degrees (sub-level 1 of step 2) with options to include synergies (sub-level 2 of step 2). The MYTILUS version as presented in Paper 4 and the Google Drive version similarly include synergies. Therefore, the SEANERGY approach fulfils the second of the three co-location recommendations listed in Paper 1: to focus on synergies and not only conflicts. However, SEANERGY only includes potential conflicts and synergies and does not list specific conflicts and synergies with socio-economic consequences such as the ones exemplified in Paper 1. Within the SEANERGY approach, conflicts and synergies are kept at an overall, general level. One could criticise SEANERGY for not diving into details. However, as Paper 2 states, *"it is the whole purpose of SEANERGY to stay at an overall level to get an overview of which spatial areas and which marine use combinations need further, more detailed exploration"*. The lack of detail allows SEANERGY to take a cross-sectoral, systematic, matrix-based approach to potential synergies and conflicts that makes up a general, pairwise use-use indexed conflict-synergy catalogue and for *"a full transboundary sea basin such as the Baltic*

Sea" at once (Paper 3: Bonnevie et al. 2020b). The Baltic Sea analysis results presented in Paper 2 and Paper 3 stay at this overall sea basin level. However, the options to update GIS data and conflict-synergy score knowledge within SEANERGY makes it flexible to different spatial scales. As Eliasen et al. (2020) points out based on an interview with this author: *"While the tool can be applied at a broad scale, the aim is also to make it operationalizable for local planners in smaller sea spaces and planning contexts – making it flexible to different geographical scales, planning levels, and users engaging in MSP."* As the SEAPLANSPACE workshop findings illustrate, conflict-synergy knowledge could be updated to reflect actual, experienced conflicts and synergies instead of the current general potential conflicts and synergies if the SEANERGY approach is used in a workshop setting surrounding a local, more specific area such as the Møn case. Such a local, explorative SEANERGY approach that updates the conflict-synergy scores would also enable the SEANERGY conflict-synergy knowledge to distinguish between synergy-occurrences of mutualism and commensalism and conflict-occurrences of amensalism and competition (sub-level 3 of step 2), a detail level not covered in the current SEANERGY knowledge. However, the conflict type antagonism would have to be approached differently. While tool 4 and 5 of the SEANERGY toolbox enables the user to avoid conflicts by locating a new marine use where it would only experience potential synergies (if such only-synergic areas exist), locating a new marine use might antagonistically decrease the space available for other, future not yet located and not yet considered marine uses. Since the SEANERGY approach does not facilitate the process of locating multiple new marine uses at the same time, future antagonism-based conflicts cannot be explored – the possibility that the distribution of space to one or more marine uses limit(s) the space available for one or more future other marine uses. However, the ability of the SEANERGY approach to optimise synergies as presented in details in Paper 2 and Paper 3 likely causes fewer future antagonistic conflicts by freeing more space for other marine uses due to an optimised use of space, enabling an indirect consideration of antagonism.

Thirdly, it has been demonstrated in this chapter how the SEANERGY approach weighs synergies and conflicts (step 3 of the stepwise framework) by providing a ranking-based approach to the conflict-synergy knowledge (sub-level 2 of step 3) through preliminary Baltic Sea scores that can be updated by the user and that goes beyond just binarily listing whether marine use pairs are mostly synergic and conflicting (sub-level 1 of step 3). This fulfils most of the third co-location recommendation in Paper 1 to rank synergies and conflicts instead of a binary approach, with the exception that risks are not considered as part of the ranking which was part of the recommendation. Paper 1 describes how potential conflicts/synergies sometimes involve risks, for example, safety risks or environmental risks. It states how *"environmental impacts are sometimes only risks not certainties that still need to be considered through a precautionary principle"*. Due to the rough detail level of and knowledge gaps of the Baltic Sea conflict-synergy knowledge inputted into

SEANERGY, the SEANERGY approach does neither score nor address the different degrees of risks and uncertainties for the potential synergies and conflicts to take place. Despite not exploring risks, the SEANERGY toolbox does, however, acknowledge that uncertainties exist through its implementation of uncertainty tests in tool 5. As shown in Paper 2, the SEANERGY uncertainty tests allow the user to be aware of conflict-synergy patterns that are sensitive to small variations in the score inputs.

Fourthly, one can argue that SEANERGY follows the co-location management stages of the stepwise framework of detecting conflicts and synergies for existing/future conditions and enabling its users to minimise/avoid conflicts while strengthening synergies. The many ways in which SEANERGY facilitates both stages through combining maps, marine use knowledge, and statistical information is demonstrated with the overall Baltic Sea analysis in Paper 2 and with the more specific examples in Paper 3. In all three SEANERGY implementations, the users can compare conflict-synergy patterns of different marine use scenarios and then prioritise scenarios with more synergies and less conflicts in trade-offs negotiations. With tool 3 and tool 4 of SEANERGY, the user can more directly increase synergies by exploring only-synergy locations for a new, not yet located marine use, as shown in Paper 2 and Paper 3. To be able to increase synergies and minimise conflicts, one can point to the necessity of being able to link conflict-synergy patterns with the marine uses producing them. In the SEAPLANSPACE workshop, it was found to be an important ability of the SEANERGY approach. The SEAPLANSPACE participants gave much attention to the marine use location maps when discussing synergies and conflicts. All three SEANERGY implementations enable the users to trace the spatial conflict-synergy patterns back to the marine uses producing them through options to visually compare score maps and marine use location maps. In the SEANERGY toolbox, as shown in Paper 3 the link is also established through options to click on a raster cell in a conflict-synergy map and explore its pairwise marine use combinations and their pairwise conflict-synergy knowledge.

Finally, the SEANERGY approach does include nature/environmental protection as requested by Paper 1. The preprocessed pan-Baltic HELCOM data includes the categories of *nature protection/Natura2000*, *marine protected areas (MPAs)*, and *protection of birds/RAMSAR*, as listed in Paper 3, and these categories were also included in the SEAPLANSPACE workshop. Furthermore, the implementation of SEANERGY into MYTILUS described in Paper 4 enables the inclusion of the CIA approach as well which was also requested by Paper 1.

Figure 19 sums up how SEANERGY follows the stepwise co-location framework. With the SEANERGY approach fulfilling all steps within the stepwise framework, the SEANERGY approach appears to be promising for co-location studies within MSP. This was confirmed by the participants in the SEAPLANSPACE workshop.

While they did state concerns for whether it is possible to find a representative ranking method, a concern that will be discussed later in this thesis, they did in their written feedback clearly confirm the importance of ranking synergies and conflicts in maps and graphs, putting the SEANERGY approach in a promising light.

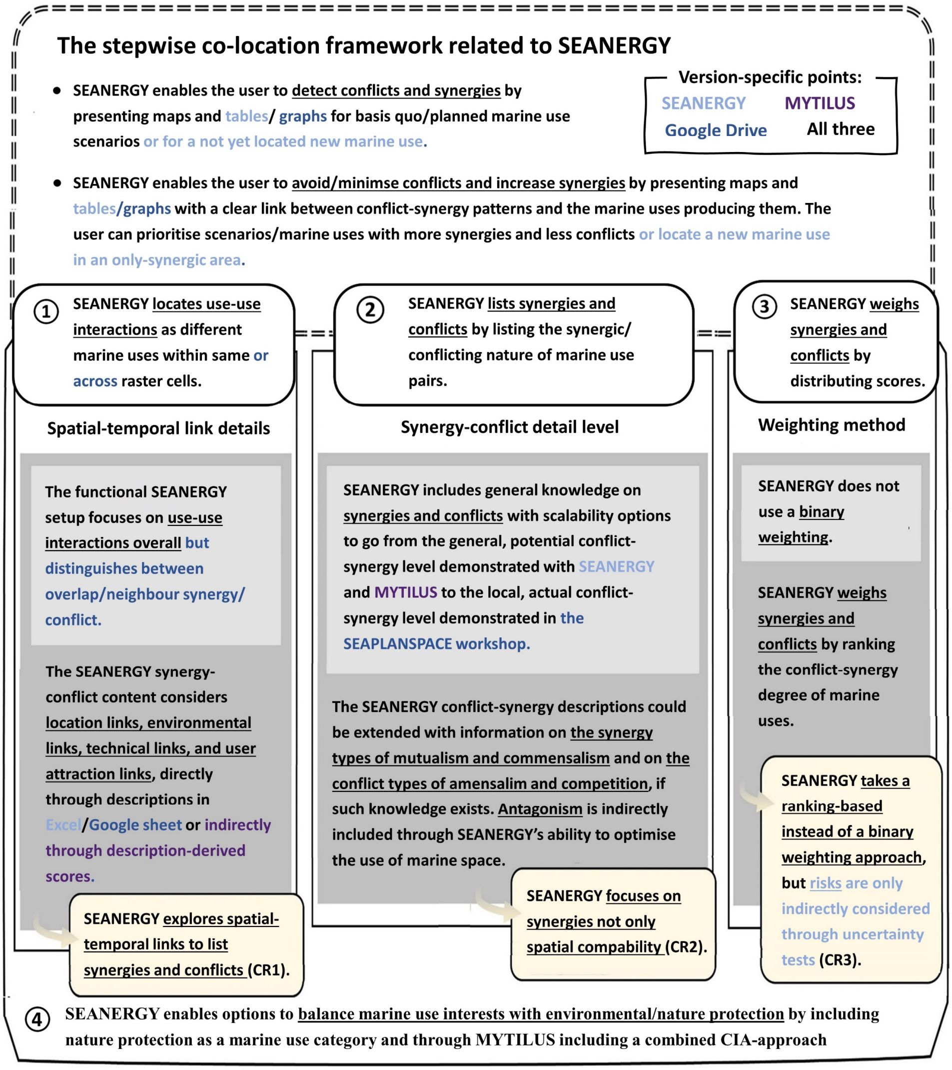

Figure 19. The SEANERGY approach related to the co-location framework. Links are visualised between the SEANERGY approach, the framework, and the three colocation recommendations (CR) from Bonnevie et al. (2019). SEANERGY version-specific points are highlighted with colour.

3.5.2. Functional abilities

Paper 2 divides its discussion of SEANERGY into reflections on SEANERGY overall, on conflict-synergy matrix knowledge, on needed analysis detail level, and on the technical implementation. Drawing on points primarily from Paper 2 but supplemented with arguments from Paper 3 and Paper 4 and with SEAPLANSPACE reflections, it will be discussed to what degree SEANERGY considers the general recommendations for spatial DSTs to aim for user ease, tool accessibility, and transparency.

3.5.2.1. User ease

As part of making a spatial DST easy to use, the three general spatial DST recommendations for user ease will be considered (R1, R2, and R3).

R1 highlights how a spatial DST must document itself well and ensure working functionality. To facilitate R1, the SEANERGY toolbox is well-documented with metadata that guides the users of how to run the different tools. As Paper 2 explains, two different types of metadata are implemented: a descriptive read-me PDF-file where the user can look up presentations of tools and Baltic Sea baseline data, and *"metadata directly implemented in the tools themselves to iteratively guide the tool users"*. When the user clicks around in the interface of a tool, the built-in metadata changes correspondingly. In the read-me file, not only the toolbox and its tools are described but also the sources and preprocessing of the Baltic Sea baseline data (Paper 2: Bonnevie et al. 2020a). The documentation of the whole process from raw data to final proof-of-concept maps can facilitate replicability and thus a higher degree of user trust (Bagstad et al. 2013). Furthermore, the SEANERGY toolbox is not only expected to work but has been demonstrated to work. The various tool functions have been tested and demonstrated through pan-Baltic Sea proof-of-concept analyses in Paper 2 and Paper 3, and through applying the methodology as part of the SEAPLANSPACE workshop to get feedback from local planners/stakeholders with an interest in MSP. Thus, the user can expect the tools to work with the toolbox being a fully functioning prototype. Eliasen et al. (2020) evaluates the SEANERGY approach to represent a mid-range technological readiness level of *TRL5 "Technology validated in relevant environment"* which is the fifth out of nine TRL levels that are defined in the HORIZON2020 material from the EC to evaluate use readiness of technologies. As Eliasen et al. (2020) explain, a relevant environment in an MSP project context could be *"events where the tool is validated (and accepted as relevant by the respective users) or where its use is demonstrated by some of the expected users applying it in a particular context or setting"*. With the testing surrounding the Danish island of Møn in the SEAPLANSPACE workshop being the relevant environment and the group work participants from environmental NGOs/local planners being the expected users, the SEANERGY approach has moved up one level from *TRL4*

Technology Validated in Lab with the pan-Baltic proof-of-concept analyses representing the lab.

R2 recommends the tasks of prioritising a simple design, train users when necessary, and optimise processing time. The toolbox design of SEANERGY allows all six tools to be combined through one interface which is *"intuitive for GIS users"*, since the user interface is already known and used in the global GIS community (Paper 2: Bonnevie et al. 2020a). However, the requirement to have a desktop GIS program installed to run a tool is an obstacle for non-GIS users in the MSP world with regards to applying the tool to actual MSP (Pınarbaşı et al. 2019). In the SEAPLANSPACE workshop, the Google Drive setup enabled the facilitator role of the SEANERGY approach *during* the workshop to be distributed out to non-GIS users due to the setup of the SEANERGY approach in an online, GIS-independent environment. However, the Google Drive setup required even further time-consuming data preparations by a GIS specialist *before* the workshop than required for the SEANERGY toolbox setup. SEANERGY's preprocessing to make the marine use GIS data comparable is already relatively time-consuming, as described in Paper 2. However, all preprocessing steps are setup in a preprocessing toolbox to automatise and ease future preprocessing, and the already preprocessed Baltic Sea GIS data and score data is free to be used as a baseline for future analyses which might speed up the preparations for future analyses. Not only the preprocessing time but also the run time of a spatial DST is an important aspect to evaluate user ease (Bagstad et al. 2013). As explained in Paper 2, the run time of SEANERGY varies with the tool and input choices. In some cases, it takes so long to run that it is unfit to be used during stakeholder workshops. Through the implementation of the SEANERGY approach into MYTILUS, as presented in Paper 4, the run time is much faster for calculating conflict-synergy scores for all pairwise combinations of uses due to the fast coding environment of MYTILUS (Hansen 2019). For the Google Drive version, the run time is likewise fast when producing total conflict-synergy scores for all pairwise combinations (Eliasen et al. 2020).

The last general recommendation for user ease is the aim for multi-functionality (R3). SEANERGY offers some degree of multi-functionality through its flexible tool choices and user choices presented in Paper 2 and Paper 3. In addition, the whole setup of SEANERGY is a qualitative and quantitative mix. The scoring provides a way to weight synergies and conflicts based on qualitative stakeholder opinions to be inputs in non-spatial and spatial quantitative measures (Paper 2: Bonnevie et al. 2020a). Integrating different knowledge sources, as was done in the SEANERGY approach, can also be a means to provide multi-functionality (Ruiz-Frau et al. 2015). In addition, as pointed out in Paper 2, it is not possible to consider co-location options with SEANERGY unless it is combined with the CIA approach. The technical integration of the SEANERGY approach into MYTILUS in Paper 4 is another way of providing multifunctionality. SEANERGY has with these small measures taken steps towards multifunctionality. Since the road towards supporting all necessary spatial DST functionalities for MSP is immense due to the ambitious goals of MSP (Pınarbaşı et al. 2017), one programmer can advantageously share the task of implementing multifunctionality with a global network of programmers, as the next section will show.

3.5.2.2. Tool accessibility

Two spatial DST recommendations focus on tool accessibility (R4 and R5). R4 highlights the importance of maintaining spatial DSTs and making them freely available for users also at longterm scale. Publishing open source is an essential step to improve tool access (Depellegrin et al. 2017). By publishing a spatial DST as open source, the code is made available for others to critically evaluate and extend, ensuring replicability and facilitating multifunctionality (Menegon et al. 2016). This was done for the SEANERGY toolbox, its preprocessing toolbox, and its baseline data (Paper 2: Bonnevie et al. 2020a). As mentioned by Pınarbaşı et al. (2017), spatial DSTs can quickly turn into scientific experiences never applied to practical use if they stop being available and/or updated.

R5 strengthens the importance of minimising license costs. The SEANERGY toolbox requires a license-based commercial GIS program to run (Paper 2: Bonnevie et al. 2020a), and thereby SEANERGY has an inherent economic obstacle to attract users, since the license costs are not insignificant. MYTILUS, on the other hand, is a free programme (Hansen 2019). Thus, the licence-caused obstacle is removed through the implementation of the SEANERGY approach into MYTILUS. However, MYTILUS is like SEANERGY a desktop-based solution, for which reason it still needs to be locally installed (Hansen 2019). The Google Drive setup, on the other hand, besides being free, is an online solution, which makes it more accessible for some users but *"requires a well-functioning internet connection and computing power"* (Eliasen et al. 2020).

3.5.2.3. Transparency

Transparency is the third functional ability to touch upon, and it follows from two general spatial DST recommendations (R6 and R7).

Regarding R6, Collie et al. (2013) describe how *"black box"* user experiences are related to challenges with not being able to *"trace decisions back to the individual information sources"*. Paper 2 highlights how *"the high degree of user flexibility of SEANERGY supports an iterative maritime spatial planning (MSP) approach."* As the SEAPLANSPACE workshop furthermore demonstrated, the SEANERGY approach can be recalculated to update maps and statistics based on changes in input scores (Eliasen et al. 2020). This provides *"clarity in the data"* which is an important part of transparency (Collie et al. 2013). With the high degree of tool user flexibility and options to change score inputs, SEANERGY users can iteratively recalculate the tools to explore different spatial and non-spatial conflict-synergy outputs. As was pointed out earlier in this thesis, all three SEANERGY versions provide a clear link between spatial conflict-synergy patterns and the marine uses producing them, which increases transparency between inputs and outputs, as per definition. Similarly, it has been pointed out from Paper 2 how tool 6 supports transparency with its ability to gain a non-spatial overview of the pairwise SEANERGY matrix content by enabling users to quickly look up specific pairwise knowledge. In addition, the availability of preprocessed data on GitHub linked with metadata increase transparency.

The recommendation to provide an uncertainty analysis (R7) is strongly related to ensuring trackability of the process from inputs to outputs, following the uncertainty analysis definition provided by Lilburne and Tarantola (2009): *"uncertainty analysis quantifies the magnitude of the resulting uncertainty in the model predictions due to uncertainties in model inputs"*. As has been shown from Paper 2, SEANERGY implements different uncertainty tests with tool 5 which increases transparency for the users, which might increase trust as well (Bagstad et al. 2013).

3.6. Chapter summary

Answers to RQ2 were provided by drawing on findings from especially Paper 2 *Bonnevie et al. 2020a* with supportive findings from Paper 3 *Bonnevie et al. 2020b* and from Paper 4 *Hansen & Bonnevie 2020*. Three implementations of the SEANERGY approach were introduced to better target use-use interactions within a spatial DST in support for MSP. The main implementation consisting of an ArcMap toolbox called SEANERGY was introduced based on technicalities presented in Paper 2 and pan-Baltic analyses presented overall in Paper 2 and in more detail in Paper 3. A second implementation of the SEANERGY approach design through MYTILUS was referenced from Paper 4 due to its strength in combining the SEANERGY approach with the CIA approach. A third implementation in a Google Drive setup was applied in a SEAPLANSPACE workshop with real stakeholders interested in MSP based on a marine Danish case near Møn island providing not yet peer-reviewed experiences.

By drawing on all three SEANERGY versions and their corresponding papers, arguments were made in favour of the ability of the SEANERGY approach to facilitate co-location options due to its resemblance with the co-location framework from Paper 1 *Bonnevie et al. 2019*. In addition, arguments were made in favour of its function abilities to facilitate user ease, tool accessibility, and transparency, for example, by providing documented metadata, GitHub-distributed source code, and an iterative design with input uncertainty tests.

Chapter 4.
The contribution of SEANERGY to integrative MSP

New spatial DSTs such as SEANERGY need to be adequately included in the MSP processes to be of actual use for MSP (Pınarbaşı et al. 2017; Gee et al. 2019). This chapter explores how the developed SEANERGY approach facilitates integrative MSP (RQ3) based mostly on Paper 3 *Bonnevie et al. (2020b)*, available in Appendix F. It aims to link SEANERGY to integrative MSP dimensions and through those links also include the MSP process by Ehler & Douvere (2009), the MSP minimum requirements (MMRs) from the MSP Directive (EC 2014), and the content-based general spatial DST requirements (CRs), to provide a coherent contribution to MSP.

4.1. An academic literature search

To enable an evaluation of how the SEANERGY approach supports integrative, transboundary dimensions of MSP, a smaller academic literature search was carried out in summer 2020, searching for *academic articles* on *"integrative MSP"* with *publication year 2015-2020* in Aalborg University Library's advanced online search function (aub.aau.dk) and the SCOPUS database. The purpose of the literature search was to find theory describing the integrative characteristics of MSP, not to systematically review a specific concept such as Chapter 2's academic literature review. As a result of the academic literature search, 10 academic articles on integrative MSP provide theoretical inputs to Paper 3. Of these, three papers Piwowarczyka et al. (2019), Gee et al. (2019), and Weig and Schultz-Zehden (2019) refer to all four analytical integrative dimensions of MSP.

4.2. Contribution to integrative MSP

The four integrative MSP dimensions, though all closely interconnected, are separated analytically and into sub-themes in Paper 3 where they are used to evaluate SEANERGY's contribution to integrative MSP. The four dimensions are, respectively:

- knowledge integration that focuses on data and knowledge,
- sector and policy integration that focuses on MSP priorities,
- stakeholder integration, and

- transboundary, multi-scale and land-sea integration which integrate across physical boundaries.

The main findings from the discussion in Paper 3 are summed up and linked to the MSP elements presented back in the introduction. Figure 20 visually presents the links to the MSP elements.

Figure 20. Overall presentation of SEANERGY's MSP integration abilities. They are more detailed described in Bonnevie et al. 2020b. They are linked here to the MSP minimum requirements (MMRs) and the content-related spatial DST requirements (Rs) from the introduction.

4.2.1. Knowledge content integration

Paper 3 links the knowledge content produced with SEANERGY to step 5 (existing conditions) and step 6 (future conditions) of the MSP stepwise guide from Ehler &

Douvere (2009). It asserts that the knowledge content from SEANERGY is more than the conflict-synergy tool outcomes, since SEANERGY can provide double-learning by also improving cross-sectoral understandings through capacity-building.

Viewed in relation to MSP and its minimum requirements (MMRs), these points on SEANERGY knowledge content have some further relevance for the MSP process. Many countries have not yet engaged with the later steps of MSP (Pınarbaşı et al. 2017). MSP is a relatively new requirement within the EU but the first plan deadline (March 2021) is approaching, for which reason the later MSP steps will soon require examination (Pınarbaşı et al. 2017; EC 2014). As pointed out in Eliasen et al. (2020), SEANERGY has the potential to contribute to *"evaluation of existing use-use conflicts/synergies"*. By using SEANERGY also in the evaluation step (MSP step 9) as an addition to MSP step 5 and 6, the SEANERGY conflict-synergy knowledge can be improved over time by drawing on conflict-synergy experiences from actual implemented plans. This fits the recommendation of the co-location framework from Paper 1 to assess conflicts and synergies not only in the planning phase but also learn from implemented plans. Furthermore, to enable MSP to benefit from potential capacity-building, an iterative process seems necessary where the improved understandings as well as the direct SEANERGY outcomes feed back into new MSP rounds. As MMR10 states, MSP is per requirement an iterative process where a plan needs to be updated *"at least every ten years"* (EC 2014 Article 6). Thus, one can argue that the SEANERGY-generated double-learning can contribute not only to existing plans but also contribute to the knowledge flow utilised in the MSP Step 10 where a new planning process brings along knowledge from the old one. Figure 21 gives a visual overview of the iterative knowledge flow of SEANERGY applied to the MSP process, a flow that explicitly facilitates MMR4 to *"promote coexistence of relevant activities"* (EC 2014 Article 5).

4.2.2. Data integration

Paper 3 highlights how the overall catalogue-based character of SEANERGY provides options to gather cross-sectoral data relatively easy and carry out conflict-synergy analyses in a systematic way for larger areas. However, it also points out data gaps consisting of missing input scores and poor resolution of some of the marine use GIS data layers.

Reflecting on these points, one can argue that SEANERGY, with its overall, cross-sectoral, and scale-flexible nature, provides options to work with MMR8 of applying *"the best available data"* (EC 2014 Article 10). The SEANERGY toolbox is currently simple in its structure where the raster resolution determines the spatial resolution of conflicts and synergies, as stated in Paper 2. However, when the conflict-synergy knowledge is extended and improved through MSP over time, so can the SEANERGY methodology and its GIS analyses improve, for example, by considering *neighbour conflicts/synergies* across raster cells if input reach distances are defined and inputted.

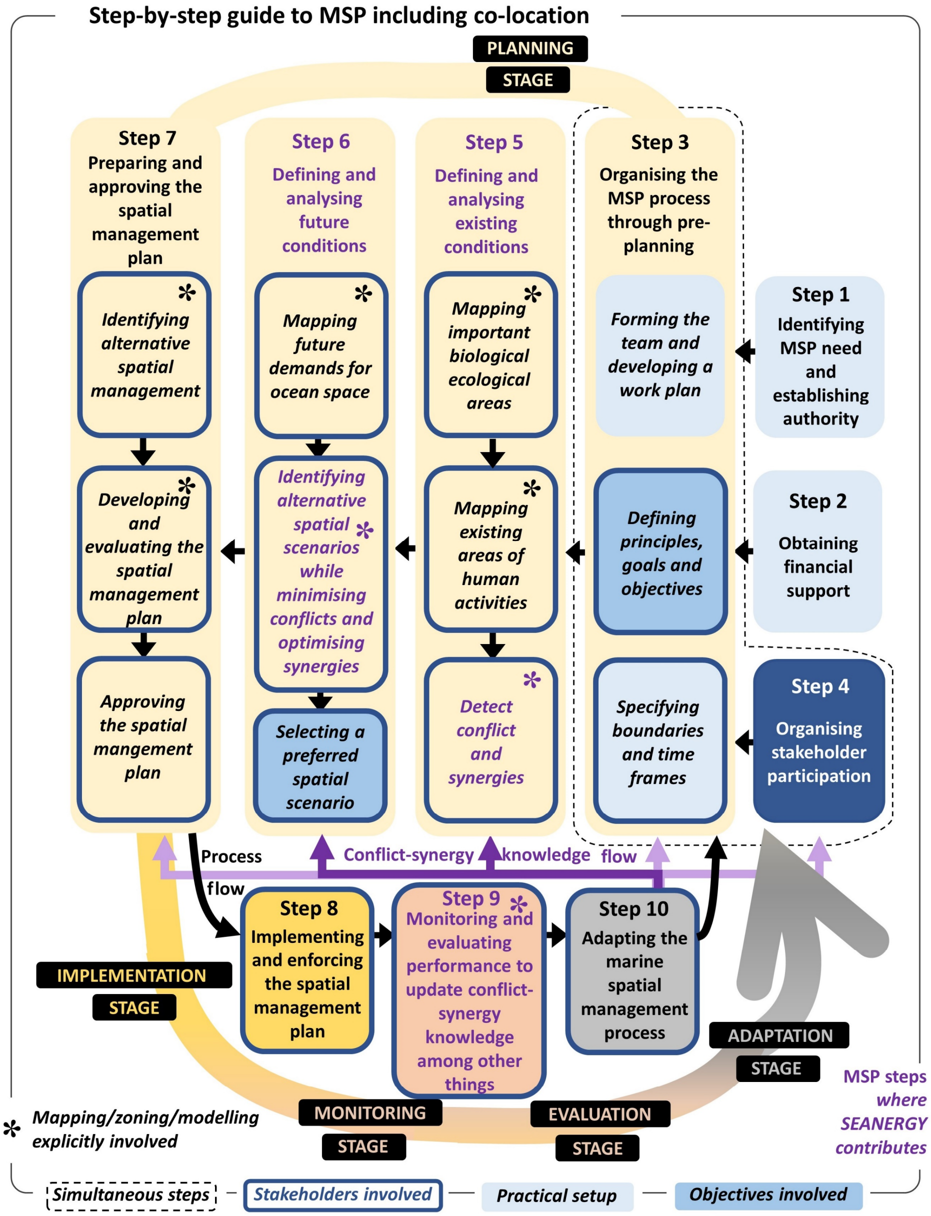

Figure 21. The conflict-synergy knowledge flow of SEANERGY linked to the MSP process. An adjustment of Figure 1 p. 3. This figure is adapted from the MSP guide by Ehler & Douvere (2009).

Currently, the uncertainty tests implemented in tool 5 only explores input uncertainties related to scores but one could argue to also explore uncertainties related to the GIS data in the form of poor resolution for the location of some marine uses, for example, fishing. As Paper 3 states, SEANERGY depends on available, harmonised data. A newer platform from HELCOM called BASEMAPS now enables countries to easily share their owns data instead of spending costly time on harmonising it across countries, thereby potentially improving the temporal resolution of Baltic Sea data.

4.2.3. Sector integration

Paper 3 discusses the difficulties for MSP to navigate between different sector interests where trade-offs are often needed and where some marine uses are given more priority than others. It asserts how SEANERGY enables better sector inclusiveness and facilitates trade-offs through its multi-sector focus spanning both economic and recreational marine uses. It also underlines how SEANERGY supplements other sector-related mapping methods, for example, suitability analyses.

When relating these points to the minimum MSP requirements (MMRs), the trend that some marine uses dominate more than others is a direct reflection of MMR11: that not all marine sectors are mandatory to include into MSP (EC 2014 Article 5). However, the MSP Directive does require the member countries to consider coexistence and to consider both environmental, economic, social, and safety aspects expressed in MMR5 (EC 2014 Article 6) which justifies a systematic multi-sector focus such as the one provided with SEANERGY. The spatial-temporal links deduced in Paper 1 seem to have some resemblance to this list of aspects. By exploring location links, environmental links, technical links, and user attraction links for potential synergies and conflicts as the SEANERGY setup enables one to do, SEANERGY helps focus on not only environmental aspects which is the traditional focus of spatial DSTs (Pınarbaşı et al. 2017), but also on socio-economic aspects, as requested by the general spatial DST recommendation R8. MMR3 which requires MSP to include *"resilience to climate change impacts"* (EC 2014 Article 5) can also indirectly be related to sector integration. Climate change can both escalate use-use conflicts and synergies due to its contribution to a changing ocean with changing ecosystem qualities causing an increasing need for co-location, and it can be a topic for sector prioritisation within MSP through the prioritisation of, for example, renewable energy sectors or coastal protection against climate change impacts (Santos et al. 2020).

4.2.4. Policy integration

Paper 3 discusses the challenges of balancing blue growth ambitions with environmental protection which is necessary for policy integration. It describes how

SEANERGY, when used alone, seems to support a soft sustainability focus where marine protected areas is one among other uses, while SEANERGY better takes into consideration the capacity of ecosystem services that so many marine uses depend on when used in combination with the CIA approach. Even though the combined SEANERGY- and CIA approach does not guarantee sustainability, it enables a better balance between soft and hard sustainability perspectives (Paper 3: Bonnevie et al. 2020b).

There is therefore an inherent challenge in MSP: to *"balance sustainable development and growth"* (MMR1; EC 2014 Article 5) with the ambition of *"an ecosystem-based approach"* and to contribute to *"the preservation, protection and improvement of the environment"* (MMR2; EC 2014 Article 5). The MSP requirement of *"an ecosystem-based approach"* attempts to link the socio-economic system with the nature-based system through the concept of ecosystems, which was illustrated with the DPSIR-extended cascade model back in Figure 3 in the Introduction. The model showed how human marine uses both depend on and impacts ecosystems through pressures. By applying a spatial marine use scenario-based approach inspired by Frederiksen et al. (n.d.) to the DSPIR-extended cascade model and by dividing use-use synergies and conflicts into *environmentally derived* versus *other/non-environmentally derived* synergies/conflicts, it is possible to illustrate how the combined SEANERGY-CIA approach works with co-location-relevant questions that follow the scenario-specific flow of change within the model. This is shown in Figure 22 that links the co-location relevant questions of a combined SEANERGY-CIA approach to the scenario-based change of introducing a new marine use to a spatial area. If such co-location questions are answered and acted on for spatial marine use scenarios, the combined SEANERGY-CIA approach supports not only a scenario-based but also an ecosystem-based approach due to the considerations given to ecosystem services. However, an ecosystem-based approach contains more than the approaches which MYTILUS and SEANERGY deliver. It also involves, for example, selecting indicators to different cascade steps to measure ecosystem-related change (von Thenen et al. 2020). Nevertheless, Figure 22 shows how the co-location-related and scenario-based questions that can be investigated with the SEANERGY-CIA approach provide inputs to an ecosystem-based approach. An ecosystem-based approach seems more achievable when applying the combined SEANERGY-CIA approach to a whole sea basin at once such as was done for the Baltic Sea in Paper 2, since coherence for maritime spatial plans across marine regions is necessary for MSP to consider the interconnectedness of ecosystems (Friess & Grémaud-Colombier 2019).

4.2.5. Stakeholder integration: Why, who, when, how

By drawing on the palette of SEANERGY intended users presented in Paper 2, Paper 3 describes how SEANERGY, while technically facilitated by GIS experts, can provide a systematic overview of multi-use potentials and conflicts of relevance for a wide spectrum of stakeholders. At a more overall planning level, MSP planners and sector representatives are targeted, and at a more local planning level, they can be supplemented with local citizens and/or local planners. Paper 3 states that an iterative communication-and-learning loop exists for the sector representatives, since they can communicate to MSP planners and other sectors their synergy/conflict viewpoints/scores by inputting them into SEANERGY while learning the viewpoints of other sectors. It asserts that such a two-way communication-and-learning process makes SEANERGY fit for finding shared goals already from the beginning of the planning process through interactive stakeholder involvement in the form of deliberation or collaboration advantageously including a communication-driven spatial DST for collaborative MSP, for example, Baltic Explorer.

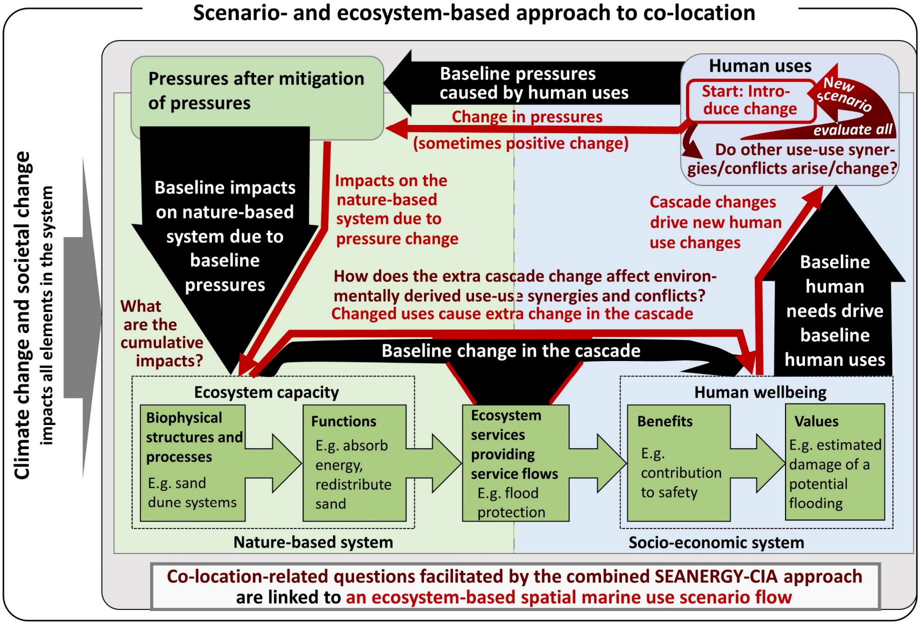

Figure 22. The contribution to an ecosystem-based approach from a scenario-based combined SEANERGY-CIA approach. A scenario-based change of the human uses, which could be the introduction of a new marine use, is introduced to the top right corner of the model that was presented in Figure 3 p. 9. The change-caused flow is represented with red arrows and linked to co-location-related questions which the combined SEANERGY-CIA approach can answer.

Stakeholder integration directly relates to MMR7, which requires MSP to include public stakeholder interaction for all *"relevant stakeholders"* at least to a *"consulting"* degree at *"an early stage"* of the planning (EC 2014 Article 9). Stakeholder interaction is also a general recommendation for spatial DSTs (R9), especially to include stakeholder values and negotiation processes to solve conflicts (Janssen et al. 2015; Ruiz-Frau et al. 2015). The SEANERGY approach follows this recommendation by enabling iterative, flexible scoring of cross-sectoral synergies and conflicts, demonstrated in the SEAPLANSPACE workshop through *in-situ* changing scores and recalculate conflict-score outputs *"based on the input of different stakeholders"* in group discussions (Eliasen et al. 2020), and resulting in the two-way process of communication-and-learning described in Paper 3. However, a challenge inherent in an iterative process that allows changing scores as the discussion moves along is the tendency for some stakeholders to exaggerate their own interests in specific areas, when met with competing claims by other sectors (Alexander et al. 2012). The participants in the SEAPLANSPACE workshop did question options to weight conflicts and synergies in a coherent way (Eliasen et al. 2020). While this can be challenging due to stakeholders having different preferences (Ruiz-Frau et al. 2015), a solution can be found by enabling stakeholders to not only communicate own interests but also find shared goals (Soma et al. 2015), a process that SEANERGY can support through its option to iteratively generate inputs to scenario-design (Paper 3: Bonnevie et al. 2020b). Through stakeholder negotiation, it is often possible to find spatial solutions for new marine uses that allow minimal disruption to existing marine uses despite opposing marine space claims (Alexander et al. 2012). The flexible approach to updating scores also enables SEANERGY to be used for stakeholder feedback later in the planning process (Paper 3: Bonnevie et al. 2020b), meeting the request stated in Pınarbaşı et al. (2017) for spatial DSTs to *"collect opinions from stakeholders"* regarding *"implemented plans"*. The option as presented in Paper 3 to use SEANERGY at two different stages of the interaction and deliberation dimension defined by Morf et al. (2019) reflects flexibility regarding the level of inclusion. One can use SEANERGY both in deliberation where *"authority keeps power to adapt process and content, without formal obligation to accommodate insights"* and in collaboration where *"tasks are defined together, based on consensus"* (Morf et al. 2019). Such a flexibility fits the flexibility allowed in the MSP Directive through MMR12: it is up to the member states themselves to determine *"how the different objectives are reflected and weighted"* (EC 2014 Article 5).

4.2.6. Transboundary integration

Paper 3 describes how SEANERGY spans different national marine waters and thereby facilitates transboundary MSP for Baltic Sea countries despite their many different MSP approaches but suggests improving SEANERGY with options to calculate country-specific sub-statistics in the future to better facilitate the national MSP processes.

The ambition of MSP for transboundary integration is reflected in MMR9: the requirement for cross-border *"cooperation among member states"* and *"with third countries"* (EC 2014 Article 11 and Article 12). The Baltic Sea has a strong tradition for collaborating across countries (Moodie et al. 2019), and the availability of data portals for the whole Baltic Sea through HELCOM reflects this. However, as the metadata links for the individual datasets presented in the SEANERGY read-me file reflect, especially data from the non-EU-member-country Russia is often missing in the applied HELCOM datasets. This is another argument for updating SEANERGY to reflect GIS data input uncertainties.

4.2.7. Multi-scale integration

Paper 3 gives details of how SEANERGY presents options to explore various spatial-temporal conflict-synergy patterns, drawing on a 4D approach to the ocean with different vertical, horizontal, and temporal characteristics as inspired from the Adriplan Conflict Score tool.

Figure 23 provides a visual summary of how SEANERGY both have similarities and differences to the Adriplan Conflict Score tool regarding the inclusion of spatial-temporal marine use attributes. Whereas the Adriplan Conflict Score tool only focus on potential conflicts, SEANERGY also enables options to explore spatial compatibility, as described in Paper 3. Furthermore, SEANERGY supports multi-scale integration in its flexibility towards spatial planning area scales. In Paper 2 and Paper 3, SEANERGY was applied to the whole Baltic sea basin, and in the SEAPLANSPACE workshop, SEANERGY was applied to a local Danish marine area (Eliasen et al. 2020). However, a limitation to this scale flexibility exists in the fact that the main SEANERGY approach only calculates conflict-synergy scores within raster cells and not across raster cells, making the conflict-synergy patterns very dependent on the raster resolution, unless more advanced conflict-synergy calculations are applied, such as was carried out in the SEAPLANSPACE workshop. Multi-scale integration is also reflected in SEANERGY's capacity to support scenarios for future marine uses, a capacity presented in Paper 2, thereby relating SEANERGY's ability for multi-scale integration to the general spatial DST recommendation of supporting future scenarios and spatial-temporal dynamics (R10).

4.2.8. Land-sea integration

Paper 3 describes how SEANERGY includes coastal marine uses that link sea and land, but could advantageously be updated to also include terrestrial coastal uses, expected to share visibility-based interactions with marine uses.

Such an expansion to also include terrestrial coastal uses was carried out in the SEAPLANSPACE workshop where visibility links between coastal summer cottages and offshore wind farms were explored and discussed (Eliasen et al. 2020), options enabled by updating the SEANERGY conflict-synergy calculations to also calculate across raster cells, not only within raster cells. The land-sea integration directly refers to MMR6 that requires MSP to consider the many interactions between land and sea (EC 2014 Article 6).

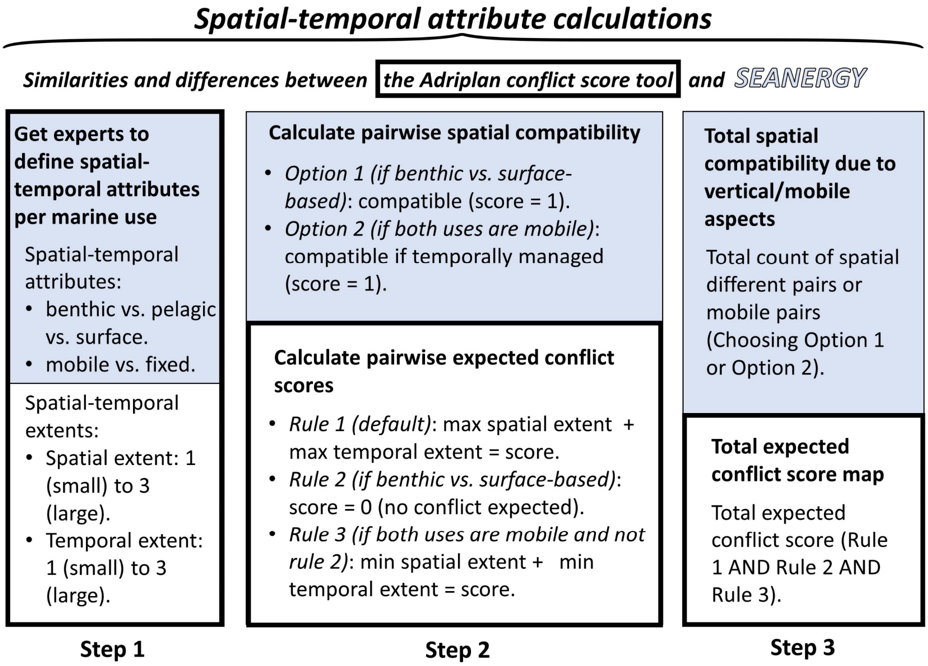

Figure 23. Spatial-temporal attribute calculations in the Adriplan conflict score tool versus SEANERGY. This figure visualises differences and similarities. The Adriplan conflict score tool description is reproduced from Schulze et al. (2013).

4.3. Chapter summary

Answers to RQ3 were provided by summarising reflections from Paper 3 to show the contribution of SEANERGY to all four analytical integrative MSP dimensions, following the same structure as in Paper 3. The discussion was extended with experiences related to the other two SEANERGY implementations when relevant. Furthermore, indirect links between the integrative ambitions of MSP and the minimum MSP requirements, the MSP process, and the general spatial DST recommendations were made explicit to clearly visualise SEANERGY's contribution to facilitate MSP in reaching the requirements stated in the MSP Directive. The reflections visualise how SEANERGY contribute to integrative MSP but also depends on MSP being integrative due to a dependency on transboundary input data of high spatial-temporal resolution.

Chapter 5.
Overall perspectives and outlook

Drawing on the findings from the previous chapters, this chapter presents some overall reflections of the PhD objective.

5.1. Main contributions

A summary of the contribution of the different papers is visually presented in Figure 24, divided into two main contributions: an analytical co-location framework and a spatial DST for co-location consisting of the SEANERGY approach.

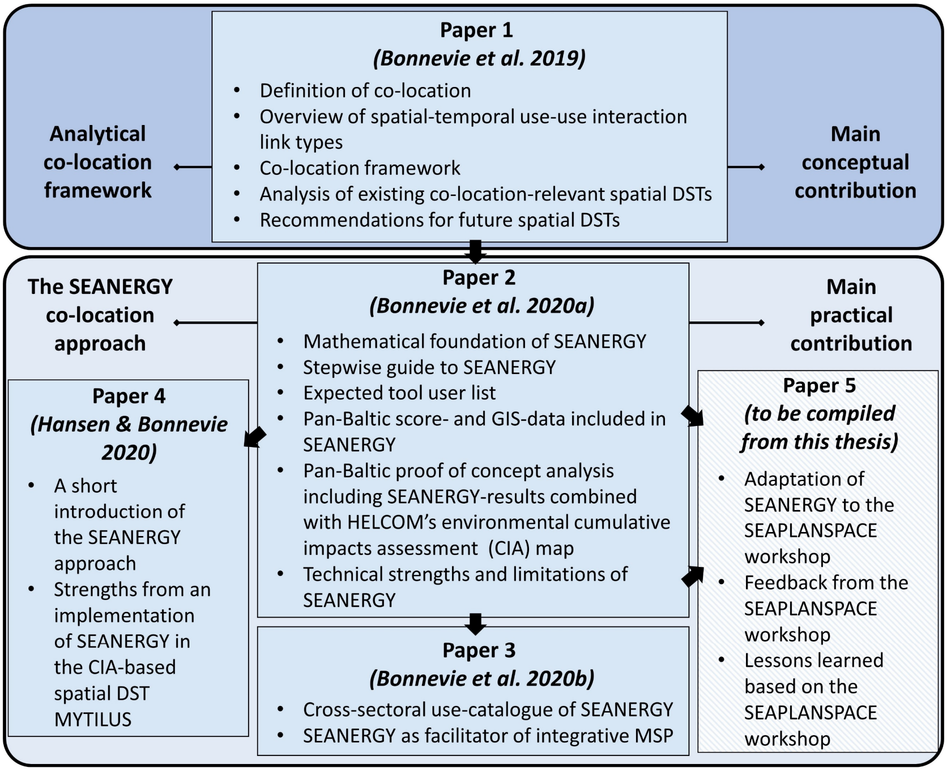

Figure 24. Main contributions of research papers. The arrows show how the papers build on top of each other. The fifth paper is to be compiled from information presented in this thesis.

5.1.1. Overall reflections on the analytical co-location framework

The co-location framework based on Paper 1 is analytical in nature, in that it reflects and systematically presents an academic understanding of the practical tasks inherent in co-location. The analytical character of the framework showed useful in analysing the strengths and limitations of existing spatial DST in contributing to co-location tasks of MSP. The framework is not only analytical, it is also conceptual in its synthesis of the co-location topic resulting in a clear co-location definition. Such a definition was needed for MSP given the lack of definitions in academic literature (Paper 1: Bonnevie et al. 2019) and the requirement in the MSP Directive (EC 2014) for the coastal EU member states to promote coexistence but without any definition of the concept. The framework is furthermore procedural. It presents practical co-location steps with the purpose of guiding spatial DSTs towards facilitating co-location. The co-location recommendations in Paper 1 highlight which parts of the framework that are particularly important to follow, to overcome the discrepancy between the high levels of details in the co-location examples in literature and the lack of details applied to co-location in existing spatial DSTs (Paper 1: Bonnevie et al. 2019). Whereas the procedural aspects of the framework target spatial DST developers, the analytical and conceptual aspects of the framework target MSP planners and MSP researchers that are given the tasks of promoting coexistence within MSP.

While this research targets coexistence within MSP, business developers outside MSP might be inspired by the concept of multi-use in the cases where economic gains could be achievable (Przedrzymirska et al. 2018). As the competition for marine space grows, it might even be business developers outside MSP that are driven towards finding new space-optimising solutions for multi-use (Depellegrin et al. 2019). Therefore, it is important for MSP planners when iteratively following the steps in the co-location framework, to embrace new multi-use potentials that might arise from cross-sectoral innovation.

5.1.2. Overall reflections on the SEANERGY approach

By following the procedural guide within the co-location framework, the SEANERGY approach emerged. The SEANERGY approach is a new, *spatial* approach to use-use interactions which includes a scenario-based focus on synergies and spatial-temporal dynamics which constitute important strengths and needs for considering co-location in MSP. The conceptual design becomes an even more important contribution when considering it as a tool for other developers to flexibly continue to work on, if needed.

The SEANERGY approach resulted in three different technical implementations with different strengths and limitations. While the Baltic Sea conflict-synergy knowledge and GIS datasets contain knowledge gaps, and often poor spatial and/or temporal resolutions, a key advantage of the SEANERGY main implementation and the SEAPLANSPACE Google Drive version are their iterative design where the tool user can explore different conflict-synergy maps, statistics, and input uncertainties and can change and add input scores to explore how it affects the outputs. The MYTILUS integration of the SEANERGY approach and the CIA approach adds the option to follow an ecosystem-based approach to the list of strengths.

5.2. Integrate SEANERGY into actual MSP

An important challenge for many spatial DSTs is that they are often not applied in actual MSP (Pınarbaşı et al. 2019). The inclusion of presentations on SEANERGY in the BONUS BASMATI deliverables were key in making MSP planners aware that the toolbox exists. It is one of the most important tasks for further research to bring the SEANERGY approach to higher technological readiness levels by applying the approach in operational environments. To facilitate such readiness, this thesis ends with three overall recommendations for further research to better integrate SEANERGY with applied MSP:

1) continue the work on applying the SEANERGY approach in stakeholder settings.
2) combine SEANERGY with other space allocation criteria needed for scenario analysis in MSP.
3) develop a systematic, stakeholder inclusive method to rank conflicts and synergies and compare their relative importance.

Whereas the two first recommendations refer to the SEANERGY approach, the last recommendation both refers to the SEANERGY approach and the co-location framework. They are the result of more general reflections on the findings of the papers, as a supplement to the more specific suggestions to further develop the SEANERGY approach that are found in Paper 2 and Paper 3.

5.2.1. Continue applying the SEANERGY approach in stakeholder settings

Three reasons to apply SEANERGY can be deduced from the findings of this research, presented in Figure 25. They can operate as inspiration for applying the SEANERGY approach as part of MSP in different stakeholder settings. The pan-Baltic analyses with the SEANERGY toolbox in Paper 2 and Paper 3 are examples of the exploration of SEANERGY outputs to learn about potential conflicts and synergies to create scenarios, which constitutes the second reason listed. The stakeholder workshop in the SEAPLANSPACE workshop with the Google Drive version is an example of exploring SEANERGY outputs with the purpose of updating SEANERGY inputs to find shared goals and update scenarios. This, constitutes the third reason listed. Further research could include stakeholder settings based on the first reason, as well, through exploring options to close knowledge gaps of the conflict-synergy knowledge in SEANERGY, and to get more conflicts/synergies and sectoral interests on the map. As Gee et al. (2017) write, *”the ability to spatially delineate”,* meaning the ability to become attached to locations on the map, can enable sectoral interests to *”be heard in decision-making”* in MSP (Gee et al. 2017). Stakeholders, which could be citizens, locals, and sector representatives, might participate in listing/ranking conflicts and synergies from their perspective to map their experiences, providing them with a location ‘on the map’, and thus make them visible for decision-makers.

Three reasons for applying SEANERGY

	MSP authority perspective	**Stakeholder perspective**	**Example of application**
1 *First reason relates to the existence of knowledge gaps*	*Gather knowledge inputs to SEANERGY* to close knowledge gaps by listing and ranking existing potential/actual conflicts and synergies *to **improve the cross-sectoral perspective**.*	*Input knowledge to SEANERGY* by listing and ranking existing potential/actual conflicts and synergies ***to be heard**/*exist on the map.	MSP planners could ask citizens and recreational organisations in an area through PPGIS to list conflicts/synergies related to spatial-temporal proximity that could then be inputted into SEANERGY.
2 *Second reason was demon-strated with the SEANERGY version*	*Explore SEANERGY outputs* by using existing conflict-synergy knowledge to explore existing/future scenarios and synergy potentials *to learn* about potential synergies and conflicts to ***create scenarios*** where *synergies are maximised* and *conflicts are avoided/minimised*.	*Explore SEANERGY outputs* by using existing conflict-synergy knowledge to Explore existing/future scenarios and synergy potentials ***to learn about potential synergies and conflicts***.	MSP planners could explore SEANERGY maps with potential conflicts and synergies between sectors in future scenarios to decide which sector representatives to invite for a workshop.
3 *Third reason was explored with the Google Drive version in the SEAPLAN-SPACE workshop*	*Invite stakeholders to explore SEANERGY outputs and update its inputs* by letting them follow purpose 2 to let them iteratively change input scores to change scenarios to ***increase plan acceptance** and **facilitate trade-off negotiations***.	*Explore SEANERGY outputs and update its inputs* by following purpose 2 but then iteratively change input scores to change scenarios ***to be heard**/*exist on the map, ***to learn other sectoral perspectives***, and *to **find shared goals***. Interactive maps are an advantage but discussions can also be initiated with static maps.	MSP planners could invite stakeholders from specific sectors that either tend to conflict or contain multi-use potential for a workshop with the purpose of finding shared goals for future scenarios.

Figure 25. Three reasons for applying SEANERGY. The reasons are suggested from the perspectives of MSP authorities and from the perspectives of stakeholders, and an application example is provided for each reason.

For reason 2 and reason 3 that explore outputs from the SEANERGY approach, such outputs can be explored in an interactive way. An interactive interface that was met with explicit curiosity and interest in the SEAPLANSPACE workshop was the Baltic Explorer interface, due to its options for browsing the locations of marine uses, looking for potential conflicts and synergies. Future SEANERGY stakeholder workshops could benefit from implementing the SEANERGY approach directly into an online, flexible, user-friendly platform such as the Baltic Explorer. Baltic Explorer includes drawing features where the user can draw on the map for interactive MSP purposes (Rönneberg et al. 2019). Further research could utilise such drawing abilities for the SEANERGY approach by enabling options to quickly calculate SEANERGY-based statistics for specific areas of interest for the user, for example, for user-drawn polygons.

In addition, further research could supplement workshops with other stakeholder engagement settings. MSP planners might sometimes prefer to include many sector representatives, and public participatory GIS (PPGIS) is a common method to involve the greater public (Voinov et al. 2018; Gee et al. 2017). As Paper 2 suggests, further research could work on methods to combine PPGIS with the SEANERGY approach, with the purpose of creating public debates and awareness regarding existing conflicts and synergies and their relative importance, and to close knowledge gaps within SEANERGY.

5.2.2. Combine SEANERGY with other space allocation criteria

Since SEANERGY is a scenario-based approach, it is important to explore how the SEANERGY approach can become aligned with other space allocation criteria for scenario analysis in MSP, a point briefly touched upon in Paper 3. MYTILUS is the first example of combining SEANERGY with another important scenario-facilitating approach for MSP. Through the combined approach, it is possible to allocate space to marine uses while considering both use-use interactions and use-environment interactions (Paper 4: Hansen & Bonnevie 2020). However, the CIA approach is not the only other spatial DST approach which provides space allocation criteria.

Improve spatial-temporal locations of not yet located marine uses: As Paper 3 points out, SEANERGY tool 3 and tool 4 do not consider operational boundaries for marine uses (see van den Burg et al. 2019 for examples of such operational boundaries), but SEANERGY assumes that all inputted raster cells are suitable for all marine uses. By combining suitability analyses with the SEANERGY approach, synergy potential areas from SEANERGY can turn more realistic, as Paper 3 points out, especially if the suitability analyses consider climate change as a factor such as Santos et al. (2020) recommend.

Specify spatial-temporal locations of already located marine uses in status quo and scenarios: In further research, methods considering the quality of marine use locations could improve SEANERGY's ability to facilitate space allocation, as briefly mentioned in Paper 3. The culturally significant area (CSA) method for prioritising only the most important locations of each use is one example of such a method (Gee et al. 2017). In addition, to enable better incorporation of uncertainties into the space allocation decisions, the uncertainty tests in tool 5 could be extended to also explore uncertainties due to poor spatial-temporal resolution regarding the quality of marine use sites.

Consider multiple not yet located marine uses: It could be an advantage to enable SEANERGY to facilitate options to locate multiple marine uses simultaneously in their most synergic area. This might be done by integrating the SEANERGY approach into Marxan With Zones which is suitable for locating multiple marine uses at once (Yates et al. 2015; Watts et al. 2009). This can minimise antagonistic relations between marine uses beyond what SEANERGY does in its current form, as its method to locate a new synergic marine use in tool 3 and tool 4 does not consider future, not yet existing nor planned marine uses that might be left with less space in the future.

By making the synergy potential areas presented with SEANERGY more realistic by including other space allocation criteria in these different suggested ways, the potential synergy areas produced with SEANERGY becomes more likely to reflect actual synergy areas. This can increase the interest for the findings among stakeholders since they are often more interested in actual synergies, which is an observation made by the Baltic Scope project (Moodie et al. 2019).

5.2.3. Develop a systematic, stakeholder inclusive method for ranking

As presented in this thesis, a key strength of SEANERGY is its flexibility in changing the conflict-synergy input scores iteratively and explore how it changes map outputs (Eliasen et al. 2020). Transparency can generate trust and thus more likelihood for tools to be used (Collie et al. 2013). However, the current scores in SEANERGY are not actual scores, as Paper 2 points out, for which reason a scoring approach is needed. The co-location framework in Paper 1 highlights the importance of weighting but does not present any method for how to do the weighting/ranking. Future research could advantageously concentrate on how to develop an approach for facilitating ranking of conflict-synergy knowledge of support for both the co-location framework and the SEANERGY approach. Research could concentrate on questions such as who are the experts to do the ranking, and how to include a wide variety of stakeholders? As Flannery et al. (2018) state, *"While MSP has the potential to democratise marine governance, we should not assume that MSP practice has 'levelled the playing field' for all stakeholders"*. Sector representatives might disagree (Janssen et al. 2015; Collie et al. 2013), and majority opinions and internal disagreements might then be necessary to facilitate (Ruiz-Frau et al. 2015). As Frederiksen et al. (n.d.) argue, the people to receive benefits and negative impacts from trade-offs are important to focus on too. A scoring approach could be systematised by considering systematic, pairwise comparison such as it is done by the analytical hierarchy process developed by Saaty (1987), applied, for example, in Gimpel et al. (2015) and Soma et al. (2014). The research would also have to consider likelihood for the conflicts/synergies to take place, risks involved, and whether some conflicts/synergies should be considered no-go, as suggested in Paper 2. However, the ranking method should not become over-complex in its methodology, risking the SEANERGY calculations turning difficult to follow and thus hinder transparency such as Bagstad et al. (2013) warn. In summary, the main challenges would be how to accommodate different stakeholder opinions and keep an overview over the relative importance distributed across different scores. As Ruiz-Frau et al. (2015) highlight, with a systematic method to enabling stakeholders to prioritise/express their opinions, *"there should be little concern that stakeholder processes result in low-quality outcomes"*. In fact, participants in a survey among end-users of tools in MSP stated that *"there are not many tools considering the human side of the equation"* such as *"social importance of marine areas"* (Pınarbaşı et al. 2019). SEANERGY can include such human sides if the scoring is implemented in a systematic way that reflects stakeholder opinions with the aim of finding what Soma et al. (2015) call *"shared policy goals"* instead of maximising individual sector gains.

Chapter 6.
Conclusion

With the EU being faced with the task of applying MSP to manage the increasing use of marine areas, the objective of this thesis was to contribute to MSP with new co-location approaches to optimise coexistence at sea. This thesis builds on the postulation that MSP with all its ambitious result-, process-, and data-related goals reflected in its minimum MSP requirements can lead to better managed marine spaces if clear MSP guidance exists. Focusing on the Baltic Sea, the research has attempted to provide clear guidance for MSP specifically related to co-location, and it has attempted to relate the co-location guidance to other requirements of MSP, to support integrative MSP. Four papers have resulted from this research, as well as material for a fifth paper which is yet to be written.

As a product of this research and the answers to its three research questions, the two main findings consist of the analytical co-location framework and the SEANERGY approach. The strongest conceptual finding of this thesis is the analytical co-location framework. It provides a definition of the concept of co-location, defining it as a dual process of *understanding* use-use interactions and *acting on that understanding* to co-locate marine uses with mostly synergies into coexistence in spatial-temporal proximity while separating mostly conflicting ones. The framework is at the same time procedural by presenting four steps for spatial DSTs to assess use-use interactions and balance use interests with environmental protection, and by recommending a scenario-based approach to optimise synergies and minimise/avoid conflicts. Its analytical aspect was demonstrated through its ability to highlight co-location gaps of existing spatial DSTs.

To meet deduced co-location recommendations based on gaps of existing spatial DSTs, the SEANERGY approach was developed and demonstrated through three different technical implementations: the SEANERGY toolbox, the MYTILUS implementation, and the Google Drive implementation with different purposes, strengths, and limitations. It has been demonstrated how the SEANERGY approach presents a new, spatial approach to an otherwise non-spatial, systematic, pairwise approach to use-use interactions. The SEANERGY approach enables a scenario-based approach to rank synergies and conflicts by following the analytical co-location framework. It is scale flexible, having been tested in pan-Baltic case studies, and having been applied in an *in-situ* group work surrounding a small, Danish marine case in the SEAPLANSPACE workshop. It considers spatial-temporal dynamics of marine uses but goes further than spatial compatibility by including synergies. It is both inspired by, and supplements, the CIA approach by enabling coexistence where the cumulative impacts on the environment are low and for a whole sea basin, thereby supporting an ecosystem-based approach to MSP.

Whilst the SEANERGY approach has been presented as an overall promising spatial DST approach, it needs to contribute to actual MSP processes and the many integrative ambitions of MSP. It has been discussed how SEANERGY supports all dimensions from knowledge integration, including data integration, to sector and policy integration, to stakeholder integration, to transboundary, multi-scale, and land-sea integration. However, it has also been stated that SEANERGY cannot remove all MSP integration obstacles and in fact, depends on integrative MSP as well. The many inherent challenges and flexibilities inherent in MSP point towards the iterative, spatial, and discussion-based sides of SEANERGY to be the most important ones for marine use scenario implementations in MSP, making multi-use potentials and trade-offs more transparent. This finding was supported by the stakeholders in the SEAPLANSPACE workshop expressing aha-moments when the conflict-synergy score outputs changed based on *in situ* changes of input scores.

The knowledge within the SEANERGY GitHub package constitutes a contribution in its own, particularly applicable to the Baltic Sea region. The synthesised conflict-synergy knowledge covers multi-use potentials, spatial-temporal compatibility, and conflict-synergy degrees for the Baltic Sea area, knowledge not often presented together in this manner within MSP. Similar conflict-synergy syntheses could advantageously be produced for other marine regions to systematically highlight synergies and conflicts due to spatial-temporal proximity. Such systematic matrices might even inspire business developers outside of MSP that aim to initiate multi-use for economic and/or space optimisation reasons.

Further research has been pointed towards continuing the work on applying SEANERGY to stakeholder settings, combining SEANERGY with other space allocation criteria, and developing a systematic, stakeholder inclusive method to rank conflicts and synergies to compare their importance. If implemented successfully, the SEANERGY approach can be of use for many different stakeholders, including MSP planners, spatial DST developers, and sector representatives, supporting foundations for an interdisciplinary and cross-sectoral approach to MSP where contributions from all sustainability dimensions are needed. If oceans contained unlimited space, one could imagine that co-location would never take place to minimise cumulative pressures on the environment. However, with the increasing claims for ocean space and the requirement of MSP to promote coexistence, the future points towards an increasing need for including co-location considerations into MSP.

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Appendices

Appendix A. The SEAPLANSPACE workshop: Day schedule

As highlighted on the project website, the SEAPLANSPACE workshop targets local and regional authorities, universities, businesses, and other stakeholders (https://seaplanspace.eu/). The 7th Danish SEAPLANSPACE workshop took place the 17th of August 2020 at Aalborg University, Copenhagen, for local Danish NGOs. It took place during the COVID-19 pandemic. The language used in the workshop was Danish. Testing the SEANERGY approach was one among multiple agendas. The topic for this workshop was specifically on sector and stakeholder perspectives on cultural heritage, recreation, and tourism approached from a sustainability perspective.

Workshop part 1: Presentations

Four different academic researchers provided presentations on their research. The research themes were as follows: *marine tourism and recreation* by senior researcher Berit C. Kaae from Copenhagen University, representing project 'havfriluftsliv.ku.dk' about marine recreation, *marine cultural heritage* by Lise Schrøder from Aalborg University Copenhagen, representing the BalticRIM project, *sustainability in MSP* by senior researcher Pia Frederiksen from Aarhus University representing the BONUS BASMATI project, and *marine use-use interactions* by Ida Maria Bonnevie (this author), representing the BONUS BASMATI project.

Workshop part 2: Group discussions – sub-divided into a group discussion part 1 and a group discussion part 2

After the presentations, the group discussions were organised. Two groups of participants were setup to discuss expected environmental and socio-economic benefits/impacts and their spatial and user-related distributions if new offshore fish farm sites (group 1) and new offshore wind farm sites (group 2), respectively, were introduced in a specific marine case study area South-East of the Danish island Møn, where real businesses have shown an interest in introducing new sites of these two marine uses. The group 1 discussion on offshore fish farms were facilitated by Pia Frederiksen, and the group 2 discussion on offshore wind farms were facilitated by Ida Maria Bonnevie (this author).

Each group discussion was divided into two parts. In the first part, the facilitator supported the discussion on benefits and impacts by clicking marine use GIS layers on and off for the geographical area in focus in Baltic Explorer, a device-flexible, free, online GIS environment, developed by the Finnish Geodetic Institute (FGI) as part of BONUS BASMATI. In the second part of the group discussion, SEANERGY methodology (not SEANERGY itself) was tested based on the previous part one discussion. During the second part of the group discussion, the participants were asked to focus on one perceived use-use conflict and/or one perceived use-use synergy of own choice that they had been discussing during workshop part 1 with regards to offshore fish farms (group 1) or offshore wind farms (group 2). The participants were asked to explore conflict-synergy maps and conflict-synergy graphs, produced previously to the workshop with the Google Drive setup, and then try to update the input score for the chosen use-use conflict and use-use synergy, to see how the change in score would cause changes in the conflict-synergy maps and graphs.

The workshop finalised the day with a written questionnaire filled in by six group discussion participants after finalised workshop. The questionnaire asked the participants to evaluate, whether they found such a conflict-synergy scoring approach useful for cross-sectoral knowledge sharing in MSP.

Participants

The workshop required sign up, but was free and open for participation, and advertised on the project homepage. Seven participants physically participated in the group discussions, making up a mix of environmental protection NGO representatives and citizens/consultants with an interest in MSP. Four people participated in group 1, and three people participated in group 2.

Appendix B. The SEAPLANSPACE workshop: Conflict-synergy knowledge

Figure B-1 and Figure B-2 show the type of conflict-synergy information requested from participants in the SEAPLANSPACE workshop. They are screenshots of the Google sheet document for group 2 (offshore wind farms) which contains information on:

- types of conflicts/synergies (neighbourhood/overlap synergy/conflict)
- conflict/synergy score size (no-go conflicts are marked with score=999)
- size of neighbourhood conflict/synergy reach distance in metres
- Expected recipients of the listed potential synergy/conflict.

The user-editable inputs we pre-inputted by this author to provide a baseline for the workshop facilitator who was free to change the inputs based on requests from participants. Arbitrary values were stated for the reach distances due to knowledge gaps since the purpose was not to quality-proof the values but to test the setup of iteratively ranking conflict-synergy scores in an *in situ* stakeholder setting.

Left document end

Activity 1	Activity 2	Type of synergy/conflict (Overlap conflict vs. Overlap synergy vs. Neighbour conflict vs. Neighbour synergy)	Description of synergy/conflict (Change or add if needed)
Windenergy [ENERGY]	Wave-/tideenergy [ENERGY]	Overlap synergy	Multi-use: The activities can share infrastructure and platform - might create an economic cluster focused on renewable energy
Windenergy [ENERGY]	Bathing areas [RECREATION]	Neighbour conflict	Bad view (according to some people) for bathing tourists due to windfarms
Windenergy [ENERGY]	Beachsport [RECREATION]	Neighbour conflict	Bad view (according to some people) for bathing tourists due to windfarms + security distance needed around windfarms
Windenergy [ENERGY]	Diving [RECREATION]	Neighbour synergy	Multi-use: Artificial reef effects from windturbines attract fishes that divers can explore + however: extra safety precautions needed due to multi-use
Windenergy [ENERGY]	Recreational/smallscale fishing [RECREATION]	Overlap synergy	Multi-use: Artificial reef effects from windturbines attract fishes that fishers could fish + however: extra safety precautions needed due to multi-use
Windenergy [ENERGY]	Recreational sailing [RECREATION]	Neighbour conflict	Extra safety precautions needed due to collision risks

Figure B-1. Screenshot of the left document end of user-editable baseline conflict-synergy inputs in the SEAPLANSPACE document. The information was provided in Danish for the workshop but has been translated to English.

‘

SCORE: Input score (integer format required): Write 999 if conflicts are considered no-go (meaning not allowed to exist); Conflicts are interpreted as negative numbers e.g. -4; Synergies are interpreted as positive numbers e.g. 2; If the conflict/the synergy is not case-relevant, leave the cell empty or write 0. Be aware: The +/- sign in front of a number is not required, since conflicts per definition are interpreted to be negative and synergies interpreted to be positive. Be aware: Only one neighbourhood conflict, one overlap conflict, one neighbourhood synergy, and one overlap synergy is allowed per pairwise marine use combination.	REACH SIZE: If neighbourhood synergy/conflict: List size of neighbourhood conflict/synergy reach in meters, e.g. write 1000 for a 1 km Euclidean distance reach size.	RECIPIENTS: Who suffers from/benefits from the conflict/synergy? With semicolon ; it is possible to distinguish between different actors.	**RIGHT DOCUMENT END**
3		Local citizens; Energy industry	
-3	1500	Bathers	
999	2000	Athletes	
3	500	Divers; Tourism industry	
3		Local fishers; Local citizens; Tourism industry	
999	500	Recreational sailors; Energy industry	

Figure B-2. Screenshot of the right document end of user-editable baseline conflict-synergy inputs in the SEAPLANSPACE document. The information was provided in Danish for the workshop but has been translated to English.

Appendix C. The SEAPLANSPACE workshop: Conflict-synergy knowledge

Data sources

The marine use GIS data used in the SEAPLANSPACE workshop consisted of nature/environment protection data from Denmark's Environmental Portal, AIS-data from the Danish Maritime Authority, Danish cultural heritage data from the BalticRIM project, and Danish marine recreation data from the Danish havfriluftsliv.ku.dk project. The locations for the suggested Klintholm mariculture, applied for by the company Musholm, and the suggested Hesnæs mariculture, applied for by the company AquaPris, were digitalised for the offshore fish farm group 1 work, based on the coordinates provided in the official applications by these companies. The suggested location for Kadetbanke wind farm was digitalised for the offshore wind farm group 2 work, based on the official Kadetbanke wind farm feasibility study document. The official mariculture applications were provided to this author by (now retired) senior researcher Pia Frederiksen at Aarhus University.

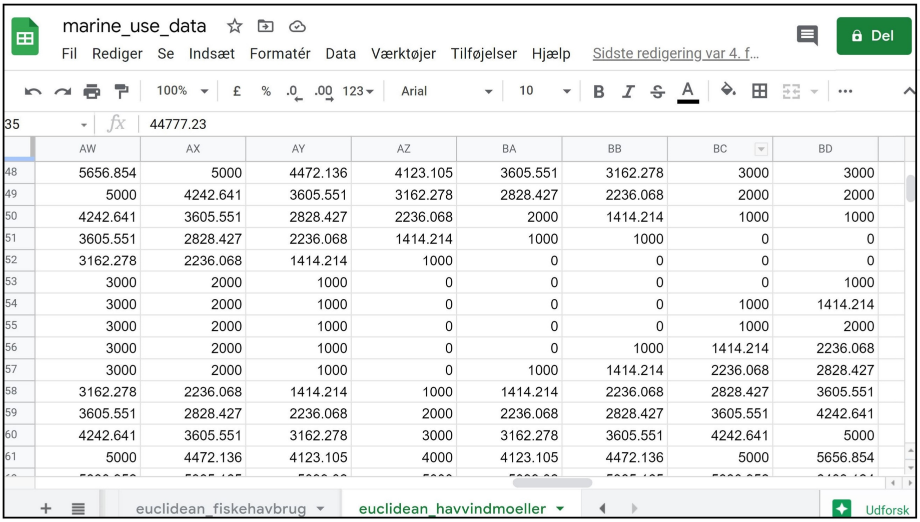
Preparing the data for Baltic Explorer as part of group discussion part 1

All the case-relevant GIS data was sent as a mix of JSON vector files and PNG raster files to the BONUS BASMATI partners from the Finnish Geodetic Institute (FGI) to enable them to include the data in the BONUS BASMATI Baltic Explorer platform. This enabled the workshop facilitators (Pia Frederiksen for group 1 and this author for group 2) to show the data on maps in Baltic Explorer to the workshop participants by clicking the data on and off in Baltic Explorer during the first part of the workshop, to facilitate the discussion among workshop participants on benefits, synergies, and conflicts.

Preparing the data for the testing of the SEANERGY approach as part of group discussion part 2

All the case-relevant GIS data were used to produce/update/present SEANERGY-based graphs and maps during the second part of the workshop. For this latter purpose, the case-relevant GIS data was converted to raster data based on the SEANERGY default raster template on a continuous scale from 0 to 1 (instead of the binary scale that was used for the SEANERGY toolbox default Baltic Sea data). The raster data was then transformed into sheets in a Google sheet document where each cell represents a raster cell, enabling the move away from the SEANERGY tool's arcpy- and spatial reference dependency. The transformation into online data enabled the data to be called with fast online Python in a Colab notebook that was linked to a Google sheet document, to produce online SEANERGY-based graphs and maps. The Google sheet document was also setup to contain Euclidean distances in metres from every raster cell in the case study area to all existing/planned offshore fish farms (group 1) or to all existing/planned offshore wind farms (group 2). The Euclidean Distance calculations were, before this step, calculated with ArcMap. The purpose of including Euclidean distances were to enable calculations of neighbour synergies/conflicts across raster cells, as an addition to the main SEANERGY approach that only calculates overlap synergies/conflicts within single raster cells.

A screenshot of the grid-based Google sheets for the offshore wind energy case is shown in Figure C-1. It shows an extract of the Euclidean distances to existing/planned offshore wind farms from each raster cell in the focus area.



	AW	AX	AY	AZ	BA	BB	BC	BD
48	5656.854	5000	4472.136	4123.105	3605.551	3162.278	3000	3000
49	5000	4242.641	3605.551	3162.278	2828.427	2236.068	2000	2000
50	4242.641	3605.551	2828.427	2236.068	2000	1414.214	1000	1000
51	3605.551	2828.427	2236.068	1414.214	1000	1000	0	0
52	3162.278	2236.068	1414.214	1000	0	0	0	0
53	3000	2000	1000	0	0	0	0	1000
54	3000	2000	1000	0	0	0	1000	1414.214
55	3000	2000	1000	0	0	0	1000	2000
56	3000	2000	1000	0	0	1000	1414.214	2236.068
57	3000	2000	1000	0	1000	1414.214	2236.068	2828.427
58	3162.278	2236.068	1414.214	1000	1414.214	2236.068	2828.427	3605.551
59	3605.551	2828.427	2236.068	2000	2236.068	2828.427	3605.551	4242.641
60	4242.641	3605.551	3162.278	3000	3162.278	3605.551	4242.641	5000
61	5000	4472.136	4123.105	4000	4123.105	4472.136	5000	5656.854

Figure C-1. Grid-based marine use location information as well as Euclidean distances in metres to existing and planned offshore wind farms gathered as Google sheets in a Google sheet document for the offshore wind farm case (group 2).

Appendix D. Paper 1

Assessing use-use interactions at sea: a theoretical framework for spatial decision support tools facilitating co-location in maritime spatial planning

Published in Marine Policy, 106, 103533

Bonnevie, I.M., Hansen, H.S. & Schröder, L. (2019)

https://doi.org/10.1016/j.marpol.2019.103533

Appendix E. Paper 2

SEANERGY – a spatial tool to facilitate the increase of synergies and to minimise conflicts between human uses at sea

Published in Environmental Modelling and Software, 132, 104808

Bonnevie, I.M., Hansen H.S., Schrøder L. (2020a)

https://doi.org/10.1016/j.envsoft.2020.104808

Appendix F. Paper 3

Supporting integrative maritime spatial planning by operationalising SEANERGY – a tool to study cross-sectoral synergies and conflicts

Published in International Journal of Digital Earth

Bonnevie, I.M., Hansen, H.S. & Schrøder, L. (2020b)

https://doi.org/10.1080/17538947.2020.1865467

Appendix G. Paper 4

A toolset to estimate the effects of human activities in maritime spatial planning

Published in: ICCSA 2020: 20th International Conference, Cagliari, Italy, July 1-4 2020. Proceedings, Part IV, Lecture Notes in Computer Science (LNCS), 12252, Springer, Switzerland, pp. 521-534

Hansen, H.S. & Bonnevie, I.M. (2020).

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