REAL-WORLD LABORATORIES AS AN APPROACH FOR REDUCING PLASTIC OUTFLOW INTO THE NORTH SEA

A case study on opportunities and risks in design and implementation in Northwest Germany

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Summary: Global plastics production has grown rapidly in recent decades and is leading to an increased discharge of plastic waste into the environment, presenting a complex socio-ecological problem. The southern North Sea and its tributaries are affected by plastic pollution due to dense population, industrial use, as well as tourism and recreational activities. A paradigm shift is necessary to reduce the outflow of plastic waste from rivers and inland waters into the North Sea. In order to foster a socio-ecological transformation, one opportunity is to involve stakeholders from all sectors, who regulate, produce, trade, use, recycle and dispose plastic products, through a transdisciplinary process. Real-world laboratories as a science-practice interaction approach are conceptualised to produce robust knowledge to solve real-world environmental and societal challenges. The aim of this study is to determine how the design and early implementation phases of real-world laboratories should be executed to achieve socio-ecological transformation. We assessed the case study of an inaugural regional stakeholder meeting of the real-world laboratory 'Plastic-FREE-sia' in Northwest Germany by in-event observations and a subsequent participant survey. Our findings of this stakeholder workshop highlight the significance of involving diverse stakeholders from multiple sectors in the real-world laboratory process and emphasise the need for balanced representation. The interests, benefits and goals of individual stakeholders must be identified from the outset and aligned with the socio-ecological problem setting, in order to prevent conflicting objectives. Concluding recommendations for the design and early implementation phases of future real-world laboratories are formulated.

Keywords: Environmental pollution, North Sea, plastic litter, real-world laboratories, stakeholder engagement, transdisciplinarity

1 Introduction

The marine environment is of global importance in terms of the provision of oxygen, food, and energy. Several economic sectors, such as trade, transport of goods, and tourism, depend on a healthy marine environment (Visbeck et al. 2014, Fleming et al. 2019). However, it is severely affected by anthropogenic activities such as habitat destruction, environmental pollution and, of course, climate change (Hoegh-Guldberg & Bruno 2010, Duarte 2014, Wittmer et al. 2021). Anthropogenic litter in particular is reported worldwide as a major threat to marine and coastal ecosystems (Wilcox et al. 2015, Canals et al. 2021, MacLeod et al. 2021), with plastic generally making up the largest proportion of litter found in the oceans and in coastal areas (Barnes et al. 2009, Lebreton & Andrady 2019). Land-based input of plastic waste into the seas is a global challenge that is predominately linked to the quality of waste management systems – or lack thereof (Jambeck et al. 2015). The North Sea is also not exempt by the above-mentioned influences (Schöneich-Argent & Freund 2020, Roscher et al. 2021, van der Molen et al. 2021). The urgency of this problem has been acknowledged by the world community and manifests in transnational agreements and initiatives, such as the formulation of the Sustainable Development Goals (SDG) of the 2030 Agenda for Sustainable Development, e.g. SDG 14 'life below water' and SDG 12 'responsible consumption and reduction' (United Nations General Assembly 2015). The current negotiations of a United Nations Plastics Treaty and the proclaimed United Nations Decade of Ocean Science for Sustainable Development (2021-2030) also highlight the importance of the problem and the pronounced dedication to address it (UNESCO-IOC 2021, March & Winton 2025). In this context, the EU Interreg North Sea project 'TREASURE'[1)] (Targeting the reduction of plastic outflow into the North Sea) aims to reduce plastic waste from rivers and inland waters into the

[1)] Project duration: 2023–2026. Lead-partner: Carl von Ossietzky University of Oldenburg

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North Sea through transnational cooperation. The collaboration between various organisations from Belgium, Denmark, France, Germany, and the Netherlands targets the development of solutions in the following four interlinked dimensions: 'governance & policy', 'prevention & behaviour change', 'data collection & analysis' and 'removal of plastic waste'. Previous studies have demonstrated that the majority of marine litter in coastal areas is deposited near its place of use (Willis et al. 2017, Stanev & Ricker 2019, Schöneich-Argent & Freund 2020). Building on these findings, region-specific solutions should be developed within each country to address all four dimensions. In order to achieve this, the 'TREASURE' project consortium aimed to apply a transdisciplinary process. A potential approach includes engaging regional stakeholders from all sectors that are involved in regulation, production, trade, use, recycling, and disposal of plastic products through real-world laboratories (RwL). RwLs are conceptualised as science-practice interaction approach, designed to produce robust knowledge with the aim of solving real-world environmental and societal challenges (Luederitz et al. 2017). Yet, a standardised definition of RwLs remains elusive (Schäpke et al. 2017). It is currently unclear to what extent RwLs can be scaled and where their limitations lie regarding participation and geographical scope. Consequently, the question arises whether RwLs can be utilised to co-create innovative solutions to large-scale socio-ecological problems, such as the influx of plastics into the North Sea.

Therefore, the aim of this study is to assess the suitability of RwLs for large-scale socio-ecological problems and to generally identify how design and early implementation phases must be realised in order to successfully develop suitable solutions. The inaugural stakeholder workshop of the German RwL 'Plastic-FREE-sia' was investigated as a case study to address the following research questions:

- What are success factors for the effective design and early implementation phases of RwLs to address large-scale socio-ecological problems?
- How does the sectoral composition of stakeholders impact RwLs?
- What are main stakeholder motivations for participating in RwLs?

It is not our objective to outline an ideal-typical design of a RwL structure, but rather to derive recommendations based on our experience to provide support for those who plan and set up future RwLs with a similar scope.

2 Theoretical framework

2.1 Plastic pollution as socio-ecological problem

Global plastic production has increased rapidly from 1.7 million tonnes per year in 1950 (Plastics Europe 2013), reaching up to 413.8 million tonnes per year by 2023 (Plastics Europe 2024). Due to its low price and versatile application, plastic has become one of the most widely used materials and forms a significant part of municipal waste (Panda et al. 2010). According to Borrelle et al. (2020: 1), in 2016 alone, approximately 19 to 23 million tonnes of plastic waste entered aquatic systems. An estimated 4.8 to 12.7 million tonnes of plastic litter entered the oceans from global coastlines in 2010 (Jambeck et al. 2015). Additionally, riverine systems as a source of marine litter must not be underestimated. Over 1,000 rivers contribute around 80% of annual ocean plastic emissions (Meijer et al. 2021). On the North Sea level, the river Elbe alone discharges up to 75.5 million items of anthropogenic litter per year into the marine environment, with the highest proportion being plastic (Schöneich-Argent et al. 2020). Moreover, a sharp increase of mismanaged and discharged anthropogenic litter is forecasted if no effective prevention strategies are applied (Jambeck et al. 2015).

Thus, plastic pollution in inland and marine systems represents a complex socio-ecological problem (Farrelly et al. 2025, Horton et al. 2025). Applying a socio-ecological lens can facilitate a more structured understanding of complex social-economic-environmental challenges. This allows for a transdisciplinary conceptualisation of the dynamic interaction between humans and the environment (Binder et al. 2013). Fundamental human needs - such as food security or transportation of goods and services - are among the key drivers of marine plastic pollution, since plastics are being extensively used across various economic sectors and anthropogenic activities. These activities contribute significantly to the resulting pressures on the marine environment, with various impacts on the entire socio-ecological system, e.g. environmentally through contamination and bioaccumulation, ecologically via plastic ingestion or ghost nets, and in terms of ecosystem services such as diminished seafood supply (Abalansa et al. 2020). As de Salas et al. (2022: 2) highlight, restoring and maintaining ocean health is a complex challenge that demands a multifaceted approach, one that considers individual, organisational, cultural, societal, and structural factors, and is adaptable enough to support context-specific solutions and drive meaningful change. Therefore,

to solve the plastic crisis - as one of the foremost socio-ecological problems of our time - holistic and transdisciplinary approaches are imperative (Holzer et al. 2018, Horton et al. 2025), since complex problems cannot be solved through a single-disciplinary approach (Binder et al. 2013).

2.2 Socio-ecological transformation and transdisciplinary research

In order to tackle major societal challenges, such as climate change or global plastic pollution, and to ensure a sustainable future, socio-ecological transformations are increasingly being advocated for fundamental changes to societal systems (United Nations General Assembly 2015, Brand & Wissen 2017, Holzer et al. 2018, Köhler et al. 2019). According to the German Advisory Council on Global Change (WBGU 2011: 1), transformation involves far-reaching changes in the areas of infrastructure, production processes, regulatory systems, and lifestyles. Hence, a reformed interaction between politics, society, business, and science is required (WBGU 2011). The scientific community seeks to fulfil its social responsibility (Cornell et al. 2013) amidst increasingly complex societal challenges (Fazey et al. 2018). Therefore, new research formats have been established in both, the environmental and sustainability sciences, and in socio-ecological research (Cornell et al. 2013). Horton et al. (2025: 3) stress the essential need for cooperation of scientists from both, environmental and social disciplines. Transdisciplinary research follows this imperative and offers the potential to analyse intricate, real-world problems, in order to develop practical solutions (Jahn et al. 2012, Lang et al. 2012, Caniglia et al. 2021, Hölscher et al. 2021). As current research shows, the integration of knowledge from different disciplines and social practice has the potential to strengthen the social impact of research (Bergmann et al. 2021). Pohl & Hadorn (2017: 1) define three phases of transdisciplinary research: problem identification as well as structuring, problem analysis, and implementing research in practice-oriented solutions. The phases are not a linear set of steps, in fact learning processes take place both in the retrospective and prospective directions (Pohl & Hadorn 2017). Similarly, the model for transdisciplinary research process by Bergmann & Jahn (2017: 1) defines the phases 'problem constitution', 'knowledge integration' and 'participation of social actors'. It is suggested that the implementation of practical solutions requires a successful cooperation between scientists and practitioners from different disciplines (Lang et al. 2012, Horton et al. 2025). With the aim to bridge 'science' and 'practice', this study follows the understanding of the transdisciplinary research process as outlined in Pohl et al. (2017: 44-45), who recognise the process as an effort of connecting two systems of knowledge production, namely the societal and the scientific process. The former process contains actors aiming to understand and address a specific societal problem based on practicability, while the latter focusses on the scientific design and research on the said problem (Pohl et al. 2017). In this context, RwLs have emerged as a science-practice interaction approach to produce robust knowledge with the aim of solving real-world environmental and societal challenges (Luederitz et al. 2017).

2.3 Real-world laboratories

RwLs are based on transdisciplinarity (Parodi et al. 2016) and are rooted in urban planning and transformative design within cities (Hossain et al. 2019). They can be characterised as a specific setup of research infrastructure or an area in which scientists and other stakeholders invent and carry out experiments to generate knowledge for a more sustainable development of society (Schneidewind et al. 2018). The research premise in RwLs consists of transdisciplinary cooperation between actors from science, politics, business, administration, and civil society. Despite the increased use of RwLs and the growing scientific debate in German-speaking countries, there is still no clear standardised definition (Schäpke et al. 2017).

However, there is consensus among the scientific community regarding main components of a RwL (Renn 2018, Schäpke et al. 2018, Singer-Brodowski et al. 2018, Wanner & Stelzer 2019):

- Direct contribution to sustainability transformation: This should be implemented by using a transdisciplinary research approach and experimental research methods (e.g. real-world experiments)
- Implementation of scientific learning, social learning and reflexivity
- Long-term orientation
- Possibility of scalability and transferability of results

There are different approaches concerning the definition and use of RwLs in various thematic areas of society (Grunwald 2015, Schäpke et al. 2017),

with hardly any restrictions in terms of thematic focus and geographical scope. It is therefore possible that RwLs cover a whole region, a city, or just individual neighbourhoods. Also, it is conceivable that RwLs are not localised at any physical location and instead relate to sectors or value chains (MWK 2013, Meyer et al. 2021).

According to Defila & Di Giulio (2019: 3), RwLs ideally pursue the following three objectives: the production of new findings/new knowledge (research objectives), the initiation of transformation processes (practical objectives) and the support of individual and collective learning processes (educational objectives). These objectives are illustrated by the typical process carried out in RwLs. Within a RwL, a transdisciplinary team proceeds through three phases: co-design, co-production, and co-evaluation. In the co-design phase, a common understanding of the problem, goals and relevant questions must be defined. The co-production phase consists of the co-developed ideas which are translated into concrete, solution-orientated experiments. Finally, the co-evaluation phase exists of the diffusion of developed knowledge in practice and science. These phases are characterised by continuous reflection and documentation of the processes and interim results (Wanner et al. 2018). Many researchers see equality among all participating interest groups as a key prerequisite for the successful implementation of a RwL (Engels & Rogge 2018, Renn 2018, Schneidewind et al. 2018, Singer-Brodowski et al. 2018). It is therefore essential that participating scientists are familiar with the research and project context (Renn 2018). This requires a certain amount of process openness and reflexivity (Rose et al. 2017, Singer-Brodowski et al. 2018). However, this does not mean, that the various players are forced to adopt a common point of view. Rather, understanding and accepting different perspectives should lead to successful collaboration (Engels & Walz 2018). Stakeholder participation can be organised differently depending on the process phase, area, and objective (Stauffacher et al. 2012). This includes, for example, workshops or bilateral agreements with key players (Pregernig et al. 2018). Also, various methods of action research are suitable for the implementation and realisation of RwLs (Scholl et al. 2018). Here, participation formats such as world-café, open space or fishbowl, are mentioned in literature (Borner & Kraft 2018).

In the last few years, new RwL approaches have also been implemented in the marine context. Topic-specific RwLs in Germany can be mentioned here: 'Good Coast Lower Saxony' ("Gute Küste Niedersachsen"), 'Knowledge Creates Living Space' ("Wissen Schafft Lebensraum") and 'Eckernförde Bay 2030' ("Eckernförder Bucht 2030"). The aim of the 'Good Coast Lower Saxony' project for example is to establish coastal protection that strengthens the ecosystem. Through the 'Knowledge Creates Living Space' project, a model region for sustainable food production at the coastal region around the harbour city of Bremerhaven should be established. The 'Eckernförde Bay 2030' project aims to reduce the nutrient inputs from agriculture into the Baltic Sea. While the project objectives of the 'Good Coast Lower Saxony' and the 'Eckernförde Bay' were more clearly defined from the outset, the project objectives for the 'Knowledge creates living space' were not defined in advance, not only to take account to the different interests of the approximately 50 stakeholders, but also because the overall objective was broader and to avoid that the involved stakeholders being spectators rather than co-creators (see Franke et al. 2023).

3 Methods and materials

3.1 Case study – RwL 'Plastic-FREE-sia'

The RwL 'Plastic-FREE-sia' was set up to target the reduction of plastic outflow into the North Sea by co-creating solutions with practitioners in Northwest Germany. The RwL was designed following the cyclical concept approached by Wanner et al. (2018: 12), whereby all actors as part of the transdisciplinary team proceed through the co-design, co-production, and co-evaluation phases. Since the subsequent phases build upon a successful initiation of the RwL, the scope of this research addresses the design and early implementation phases of the RwL 'Plastic-FREE-sia', building up a transdisciplinary team and further develop and carry out real-world experiments to reduce plastic outflow into the North Sea (Schäpke et al. 2018, Schneidewind et al. 2018, Wanner et al. 2018). Similar to the 'Knowledge creates living space' project, a pre-formulation of concrete project goals was avoided to keep the transformative process within the RwL 'Plastic-FREE-sia' as open as possible (see Franke et al. 2023). It was important to build up an interdisciplinary project research team that consists of scientists and practitioners with several backgrounds (Lang et al. 2012, Horton et al. 2025), such as economic and environmental scientists, geographers and experts in policy and governance. Our common starting point was

the identification of a study area that would allow for the implementation of a RwL with a broad range of stakeholders from several stakeholder groups in order to build up a transdisciplinary setting to carry out actions in all four 'TREASURE' project dimensions ('governance & policy', 'prevention & behaviour change', 'data collection & analysis' and 'removal of plastic waste') and therefore, to reduce plastic outflow into the North Sea. There are no uniform recommendations regarding the spatial scope of a RwL (MWK 2013, Meyer et al. 2021). According to Rose et al. (2019: 5), the extent to which the spatial scope influences the implementation of a RwL remains unclear. To cover all four project dimensions, we defined the following requirements for the geographical scope of our regional RwL: the study area should encompass not only the municipal level, but also urban and rural districts, as well as state authorities that can be integrated into the RwL-process. A broader study area would allow us to cover a larger spectrum of potential stakeholder groups and therefore, increase the possibility of knowledge production, also because not all relevant stakeholder groups can be found on the municipal level alone. Considering the overall project goal and its focus on riverine systems, it was pivotal that at least one major river of the wider Weser-Ems Region - our focus area in which the RwL was originally planned for - is covered by our study area. Ultimately, the identification of our study area was also contingent on its ability to incorporate municipalities participating in the model region *Wadden Sea Biosphere Region of Lower Saxony* (Biosphärenregion Niedersächsisches Wattenmeer), a hub for sustainable development initiatives in the wider Weser-Ems Region. Based on these criteria, we identified the study area for the regional RwL 'Plastic-FREE-sia' shown in Fig. 1.

The study area of the RwL 'Plastic-FREE-sia' covers the urban district Wilhelmshaven, as well as the rural districts Friesland and Wesermarsch. It consists of urban and rural landscapes, tidal influenced creeks, drainage ditches, the Jade Bight and the tidal river Weser. In addition, several industries are located within the region, above all the service sector including tourism (IHK 2023a, IHK 2023b, IHK 2023c). The study area is of particular inter-

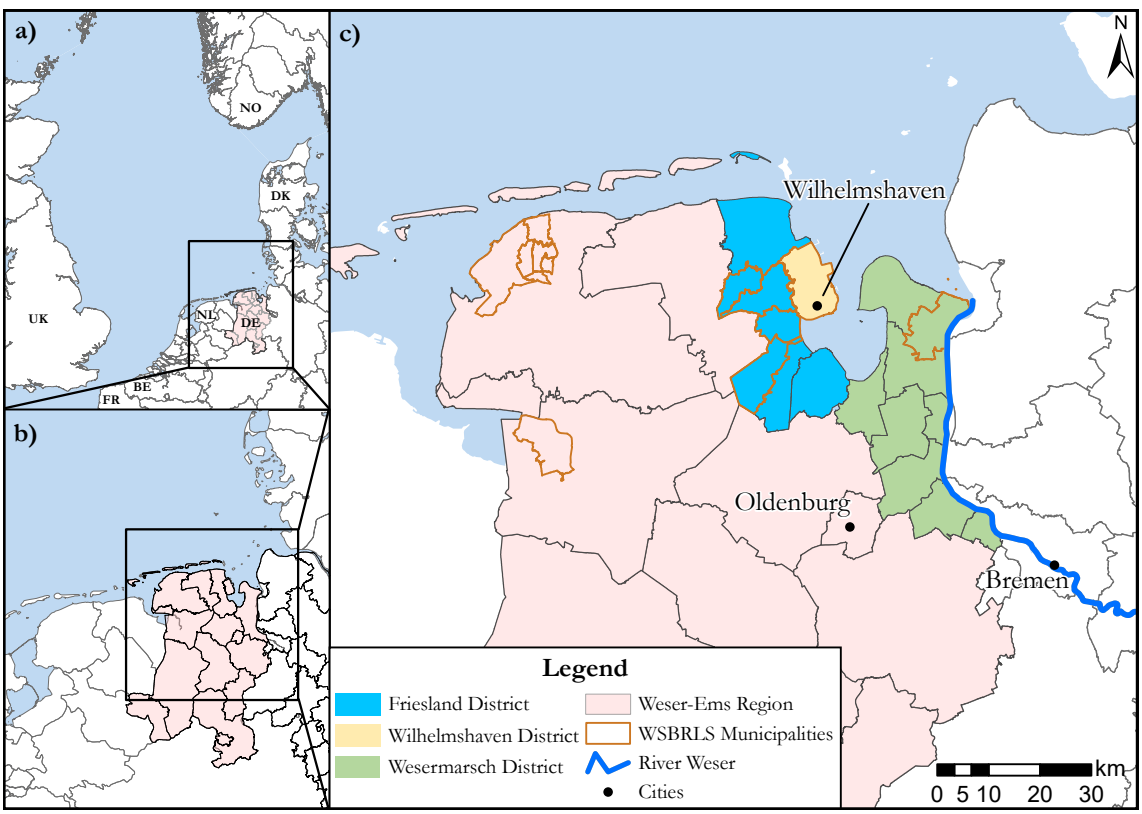

Fig. 1: Spatial scope of the German regional RwL 'Plastic-FREE-sia' on the East Frisian peninsula in the Weser-Ems Region in Lower Saxony, Northwest Germany. Wadden Sea Biosphere Region of Lower Saxony Municipalities (WSBRLS) outlined in ochre. Geodata Sources: Flanders Marine Institute 2018, ESRI 2023, LGLN 2024.

est for the implementation of our regional RwL, as it allows us to leverage a well-developed network of stakeholders who have been engaged in predecessor projects. As a result, there is already a high level of awareness regarding the issue of plastic pollution among various actors within the study area, creating a strong foundation for our initiative (Meyerjürgens et al. 2023).

3.2 Stakeholder identification

The involvement of various regional stakeholder groups is crucial for the implementation of the RwL 'Plastic-FREE-sia', to establish a transdisciplinary setting and to co-create solutions for the reduction of plastic outflow into the North Sea (Lang et al. 2012, Arnold & Piontek 2018, Singer-Brodowski et al. 2018). We could build up on extensive knowledge and experiences working with regional stakeholders in the study area due to predecessor projects dealing with plastic pollution (Meyerjürgens et al. 2023). To ensure effective transdisciplinary cooperation throughout the RwL-process, which involves actors from science, politics, business, administration, and civil society, we have taken a comprehensive approach to identify relevant stakeholder groups and sub-groups (Schäpke et al. 2017). Due to the fact that we address four different project dimensions and based on analyses from predecessor projects and our project research team's expertise, we have identified essential stakeholder groups for the RwL 'Plastic-FREE-sia' as outlined in Tab. 1.

We engaged with stakeholders all over our study area and therefore, within all administrative divisions of the regional RwL 'Plastic-FREE-sia' (Fig. 1). During the stakeholder mobilisation process, we tried to cover all stakeholder groups (Tab. 1), yet not all of them are equally distributed among our study area. We started from our existing stakeholder networks within the spatial delimitation of our study area and made use of snowball sampling, whereby contacted stakeholders were shortly interviewed for further organisations which should be involved into the RwL-process accordingly. Furthermore, we took advantage of the municipality network *Wadden Sea Biosphere Region of Lower Saxony* (Biosphärenregion Niedersächsiches Wattenmeer), as well as of the certificate 'Nationalpark Partner' awarded by the *Lower Saxon Wadden Sea National Park* (Nationalpark Niedersächsisches Wattenmeer). We assumed that partner municipalities and certified organisations are more willing to participate in our RwL. It was not always possible to identify several stakeholders of each group. To tackle this limitation, chambers or associations who represent a certain stakeholder group were considered instead (Eckart et al. 2018). In cases where stakeholders operated outside but influenced the study area, they were still considered. In total, we identified 132 potential organisations in 18 groups (Tab. 1). All stakeholders were contacted by phone or e-mail. If possible, first contact was made via phone. We reached out and pitched the overall project at first and invited them to participate in the RwL-process. In total, 68 organisations agreed to participate, whereby 39 of them joined the first regional stakeholder meeting.

3.3 Regional stakeholder meeting

Co-design workshops with numerous stakeholders are especially important for the beginning of a RwL-process to generate ideas for potential solutions and to achieve an open exchange (Bergmann et al. 2021). A regional stakeholder meeting was carried out to build up a transdisciplinary team and to generate a common problem definition among the participating stakeholders (Wanner et al. 2018). In total, 54 individuals from 39 organisations joined the meeting (Tab. 1). The event was divided into two parts (Fig. 2): the first half of the event served the elaboration of a common problem definition between participants. Selected practitioners presented their experiences on the topic of plastic reduction. To cover a diverse setting of presenters, we invited experts from education, art and culture, maritime industry, nature protection, public administration, and science to share their perspective on the problem of plastic outflow into the environment. The second half of the regional stakeholder meeting consisted of a stakeholder workshop to foster knowledge production and therefore, to generate ideas for potential solutions, the so-called 'real-world experiments' (Wanner et al. 2018). To translate the ideas from the RwL into practice, a transfer of stewardship has been proposed, involving the initiation and implementation of identified main actions by key players within their respective areas of competence. Our additional objective was therefore to identify key stakeholders who would assume decisive leadership and responsibility for the project implementation of the real-world experiments, specifically regarding the fact that the capacities of the project management team are limited and that the project covers four different dimensions.

Tab. 1: Overview of the number of organisations which were identified/contacted and of those that have participated during the RwL 'Plastic-FREE-sia' regional stakeholder meeting

Stakeholder group	Contacted organisations	Participating organisations at 'Plastic-FREE-sia' stakeholder meeting
Administration & Politics	**30**	**13**
Municipalities	17	6
High Level Authorities/State Authorities	7	4
Rural Districts	2	2
Urban District	1	1
Water & Drainage Boards	3	0
Education, Art & Culture	**13**	**8**
Cultural/National Park Centres & Museums	11	6
Schools	2	2
Industries	**67**	**10**
Agriculture & Fisheries	5	0
Industry Representatives	3	1
Logistics & Packaging	7	1
Maritime Industry	8	2
Retail & Trade	4	0
Waste Management	3	1
Tourism & Recreation	37	5
Tourism Organisations	(7)	(2)
Hotel Businesses	(14)	(2)
Wadden Sea Guides	(4)	(0)
Sailing Clubs & Marinas	(12)	(1)
NGO's/Civil Society	**22**	**8**
Total Organisations	**132**	**39**

In the first part of the workshop, a best-practice mapping was conducted. While this method does not claim to identify the definitive best case within the study area (Bretschneider et al. 2005), it served as source of inspiration by highlighting existing initiatives in the region to inform the development of potential real-world experiments. Therefore, name tags of all attending stakeholders were assigned to specific colour codes: rural district Friesland (blue), rural district Wesermarsch (green), urban district Wilhelmshaven and stakeholders that are located outside the spatial boundaries of 'Plastic-FREE-sia' (yellow). As part of the mapping exercise in the first workshop phase, all stakeholders were asked to indicate known initiatives for reducing plastic waste in their region on a map (Fig. 3). Every group (blue/green/yellow) had their own identical map and individuals made use of the exercise to exchange and create knowledge within their group. The purpose of this exercise was to foster collaboration and inspiration about what has been already done within the geographical boundaries of the RwL 'Plastic-FREE-sia' regarding the topic of plastic waste reduction.

The second and main part of the workshop focused on transdisciplinary knowledge production and on the development of potential future real-world experiments. The world-café format presumed to be an appropriate method for a mixed researcher-practitioner setting and is well suited to exchange perceptions and to identify current issues which were our main needs for the co-design phase (Silva & Guenther 2018). The approach helps to build personal relationships and to foster collaborative learning (Fouché & Light 2010). In the second phase of the workshop, stakeholders self-assigned to one of four discussion tables - 'Behaviour Change', 'Leisure & Recreation', 'Maritime Industry', and 'Waste Disposal & -Reduction' - based on their interests and expertise (Fig. 2). These thematic tables were defined in advance by participants using an online collaboration tool during the stakeholder meeting.

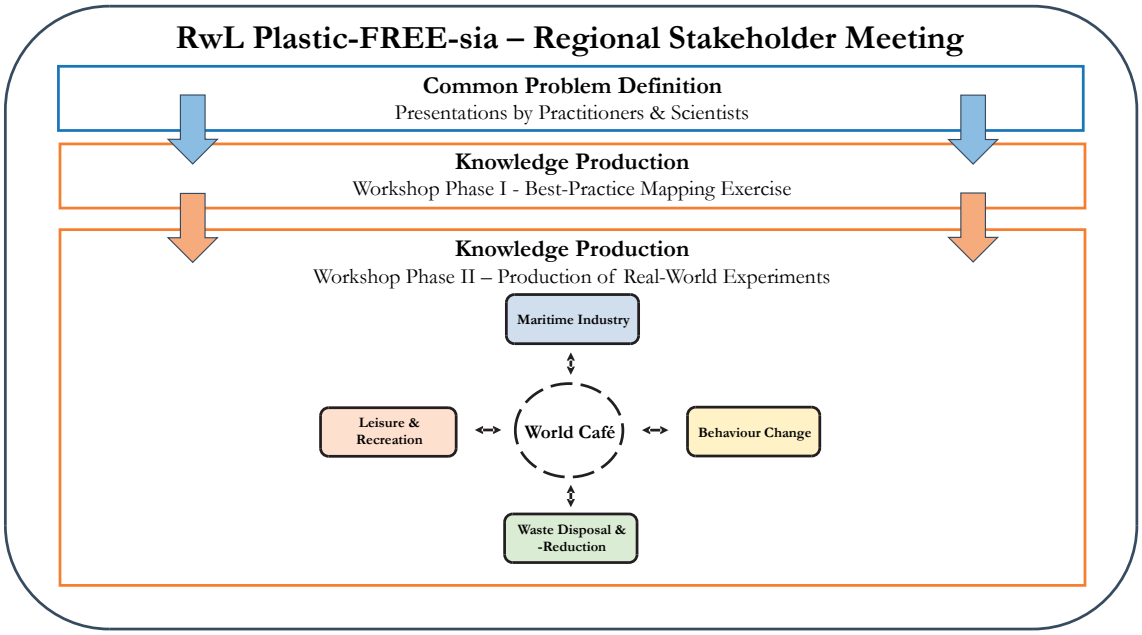

Fig. 2: Course of the RwL 'Plastic-FREE-sia' regional stakeholder meeting: I) common problem definition among participants and II) two workshop phases for knowledge production

The four discussion tables featured a diverse range of participants, with a total of 5 to 13 stakeholders from various sectors. The discussions at each table were moderated by experts of our project research team, while the overall goal of this exercise was to collect ideas about possible actions and solutions on the reduction of plastic waste that could be further developed along future real-world experiments, covering all four project dimensions in the best case. All suggestions and ideas were collaboratively collected and clustered on paper (Fouché & Light 2010).

3.4 Data collection

3.4.1 Workshop observation

Throughout both phases of the regional stakeholder workshop (Fig. 2), data was collected through an open and participant observation. The method is suitable to empower quality of data that is obtained throughout the research process and to enhance the quality of the interpretation of data and therefore, it can be used universal as part of data collection and analysis (Dewalt & Dewalt 2011). Prior to the regional stakeholder meeting, an observation template for both workshop phases was developed to observe and record behaviour and interactions of stakeholders (Tab. S1). According to Evans et al. (2015: 1), it can be beneficial for applied sustainability issues to involve students in the collaborative process. Throughout the co-design phase of our regional RwL, we worked closely with a group of university students and collaboratively developed the observation template and integrated them into the regional stakeholder meeting. The participant observation was carried out by two students and one researcher per group during both workshop phases. The stakeholders were observed for a total of 20 minutes during the best-practice mapping exercise, and for 45 minutes during the world café exercise. The observation of the event was communicated with the participants beforehand. The collected data is confidential and will not be shared publicly.

3.4.2 Online survey

Two online surveys were conducted for an in-depth evaluation of the inaugural stakeholder workshop and the co-design phase of the RwL-process. The surveys were designed to answer the research questions, addressing the success factors for the effective design and early implementation phases of RwLs to address large-scale socio-ecological problem settings. Primary data collection through surveys was ideal for our purpose, since we wanted to gather both, quantitative and qualitative data, from all participating organisations (Taherdoost 2021). Questionnaire A (Tab. S2) was developed for all stake-

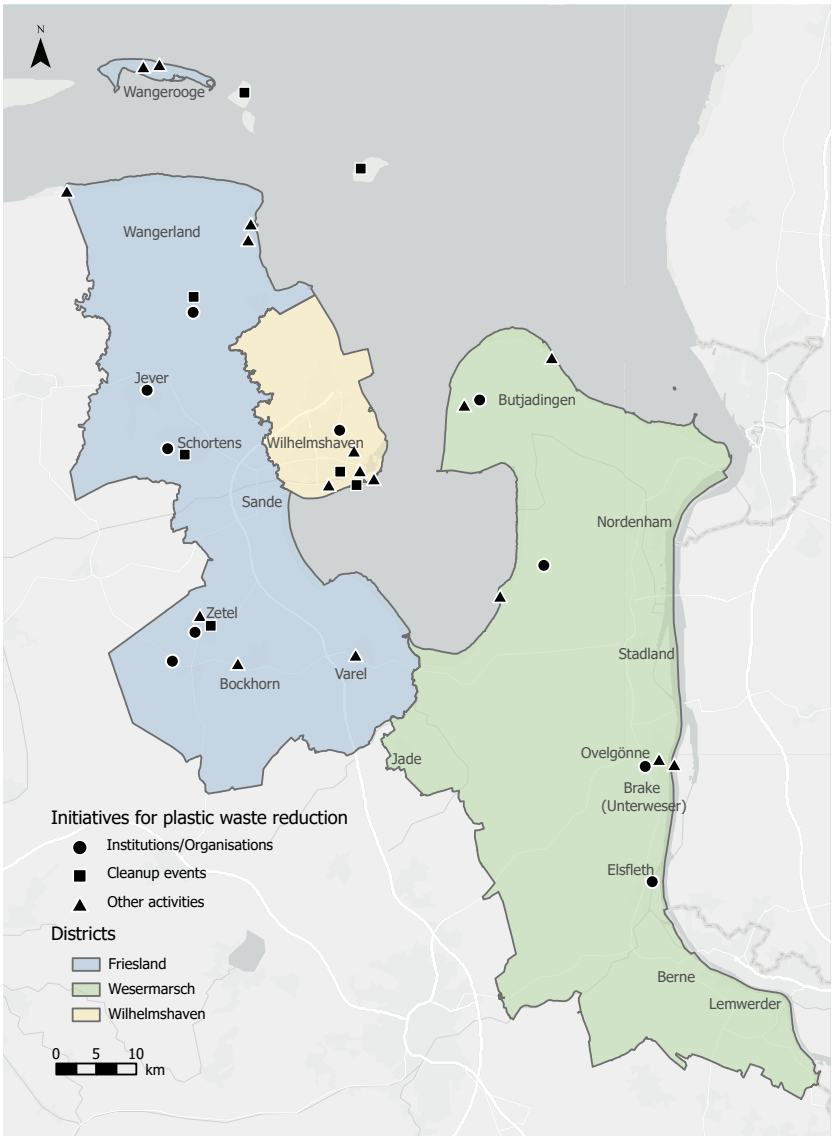

Fig. 3: Results of the best-practice mapping exercise. Spatial scope of the German regional RwL 'Plastic-FREE-sia'. The icon shape indicates the type of initiative for plastic waste reduction. Geodata Sources: ESRI 2015, LGLN 2024.

holders who were attending the regional stakeholder meeting, while questionnaire B (Tab. S2) was slightly adapted for those that could not attend the event but still wanted to participate in the RwL 'Plastic-FREE-sia'. Both questionnaires were identical in structure, with the exception that questionnaire A included additional questions related to the stakeholder event, specifically the workshop. Questionnaire A was distributed among 39 representatives from all 39 participating organisations. Additionally, to cover the scientific perspective, two experts from our project team, were selected for the survey, since they attended the stakeholder meeting and are equal participants of the RwL-process. Questionnaire B was forwarded to 29 representatives from 29 organisations. We contacted only one individual per organisation and considered them as representative, even sometimes more than one individual per organisation attended the stakeholder meeting or took part in the RwL-process. Over the four-weeks runtime, 29 individuals responded on questionnaire A, resulting in a response rate of ~74%. Two individuals provided incomplete responses and were therefore excluded from further analysis. 14 individuals responded on questionnaire B, resulting in a response rate of ~48%. Similarly, two individuals provided incom-

plete responses and were therefore also excluded from further analysis. Accordingly, 27 responses on questionnaire A (N=27) and 12 responses on questionnaire B (N=12) were considered relevant for data analysis. The collected data is confidential and will not be shared publicly.

3.5 Data analysis

Data was analysed using R Studio Version 4.2 (R Core Team 2024). To reduce dimensionality, we performed a Principal Component Analysis (PCA) using the R packages 'prcomp', 'FactoMineR' (Lê et al. 2008), and 'factoextra' (Kassambara & Mundt 2020). PCA is a widely used statistical technique in various fields to identify underlying patterns and relationships in multidimensional data, e.g. in studies on urban sustainability (Nevens et al. 2013, Lilai et al. 2016) and analyses of public perceptions on climate change (Howe et al. 2015). To assess non-linear relationships between variables in questionnaire A, distance correlation was calculated using package 'energy' (Rizzo & Szekely 2024), allowing to capture dependencies that traditional Pearson or Spearman correlations might miss. To compare the two questionnaires A and B (Tab. S2), a Tukey's Honest Significant Difference (HSD) test using package 'stats' was applied.

4 Findings

The main results of the participant observation and the subsequent online surveys are summarised below. The sector distribution of respondents from both questionnaires, A and B, is outlined in Tab. 2.

Tukey HSD comparison between the two questionnaires revealed a difference of -0.058 (95% *CI*: -0.1370.021, p^* =0.14), indicating no significant variation between groups. While the lack of significance suggests that the two groups share similar perspectives, this finding is particularly relevant when considering the alignment of ideas and motivations. Participants of questionnaire B, despite not attending the regional stakeholder meeting, expressed similar views on sectoral inclusion, shared goals such as addressing plastic pollution, and equality in collaborative processes. This alignment suggests that the workshop's themes and objectives resonate beyond those directly involved in the event, highlighting a broader consensus on the key factors that motivate participation and engagement. The PCA revealed two main dimensions (Dim1 and Dim2) that explain most of the variability in the data set (Tab. 3). These dimensions represent clusters of variables that influence different aspects of participant perceptions and attributes.

Most influential components were related to satisfaction with the workshop as well as perceived benefit for the organisation and sectoral distribution (Fig. 4). The PCA revealed data patterns and correlations between PCA dimensions. Participants who perceive long-term benefits for their organisation (QA12) also report higher satisfaction with workshop outcomes (QA20). Also, there was a strong correlation between shared problem understanding (QA9) and the suitability of RwLs to solve societal issues (Q7). The involvement of stakeholders from own sector (QA24) and Q7 was negatively correlated. A moderate positive correlation was observed between QA17 (Equality among participants) and QA26 (Involvement of business sectors) (R_d= 0.596). Similarly, moderate positive correlations (R_d= 0.565) were noted between QA26 and Q2 (Importance of plastic pollution in professional or voluntary work), and between QA8.10 (Involvement of Nature Protection in RwLs) and QA26 (R_d= 0.365). Strong positive correlations (R_d= 0.862) were found between Q7 (Suitability of RwLs to solve societal issues) and QA12 (Long-term benefit for organisation), and between QA12 and QA20 (Satisfaction

Tab. 2: Total amount of responses to both questionnaires, A and B, per stakeholder group. Three respondents have not provided information about their sectoral affiliation.

Stakeholder Group	Questionnaire A	Questionnaire B
Administration & Politics	8 (29.63%)	1 (8.33%)
Education, Art & Culture	6 (22.22%)	1 (8.33%)
Industries		
Agriculture & Fisheries	1 (3.70%)	2 (16.67%)
Logistics & Packaging	1 (3.70%)	0
Maritime Industry	1 (3.70%)	2 (16.67%)
Waste Management	1 (3.70%)	0
Tourism & Recreation	0	4 (33.33%)
Nature Protection	4 (14.81%)	1 (8.33%)
Science	2 (7.41%)	1 (8.33%)
N/A	3 (11.11%)	0
Total Responses	27	12

Tab. 3: The two dimensions, Dim1 and Dim2, explain most of the variability in the data set

Dimension	Variable	Description	Contribution
Dim1	QA16	Relevant discussion table during workshop	0.991
Dim1	QA22	Rating of world café format	0.988
Dim1	QA13	Interest in continued participation	0.987
Dim1	QA12	Long-term benefit for organisation	0.987
Dim1	QA9	Shared problem understanding	0.986
Dim1	QA17	Equality among participants	0.986
Dim1	QA19	Incorporating and developing personal ideas	0.986
Dim1	QA20	Satisfaction with workshop outcomes	0.984
Dim1	Q4	Fields for plastic reduction	0.306
Dim1	Q1	Personal experiences regarding plastic pollution	0.283
Dim2	QA8/QB8	Sectoral relevance in RwL-process	0.998
Dim2	QA14	Reasons for disengagement	0.989
Dim2	QA15	Reasons for potential disengagement	0.989
Dim2	QA18	Additional information regarding equality among participants during workshop	0.989
Dim2	QA21	Reasons for dissatisfaction with workshop outcomes	0.989
Dim2	QA23	Potential improvements of knowledge production	0.989
Dim2	QA16	Relevant discussion table during workshop	-0.081
Dim2	QA22	Rating of world café format	-0.080
Dim2	QA13	Interest in continued participation	-0.080
Dim2	QA12	Long-term benefit for organisation	-0.080
Dim2	QA17	Equality among participants	-0.080
Dim2	QA19	Incorporating and developing personal ideas	-0.080

with workshop outcomes) (R_d = 0.596). A moderate correlation (R_d = 0.453) was also identified between QA28 (Cooperation of various stakeholders from different sectors) and QA10.4 (Networking as reason for participation). Participants' perceptions of equality were negatively associated with QA16 (Relevant discussion table during the workshop) (R_d = -0.694). Conversely, participants who prioritised QA26, reported higher equality perceptions.

The majority of respondents participate in 'Plastic-FREE-sia' because of the solution-oriented character of RwLs (Questionnaire A: 24/27; Questionnaire B: 11/12). This was followed in questionnaire A by cooperation with other stakeholders (17/27) and networking (16/27). In questionnaire B, personal interest (5/12) was followed equally by taking influence (4/12) and stakeholder cooperation (4/12). Our workshop observation revealed that regional stakeholders were often aware of initiatives that are carried out within their own sector, e.g. awareness raising campaigns highlighted by educational organisations. Most of the participating stakeholders are already sensitised to plastic waste reduction and have a common ground due to their regional affiliation, know each other and initiatives that were mentioned during the best-practice mapping exercise, to a great extent. Related sectors are already cooperating with each other on plastic reduction, partly also cross-sectoral. During the second workshop phase, a heterogeneous composition of stakeholders at all discussion tables (Fig. 2) was observed. All other tables were mixed as well and no accumulation of sectors was documented. A notable exception was perceived among educational organisations at the table 'Behaviour Change'. Responses to QA24/QB11 (Involvement of stakeholders from own sector) were diverse, while six people strongly agreed, ten somewhat agreed, six somewhat disagreed, four strongly disagreed and eight were neutral. Further, 29 out of 39 respondents strongly agreed with QA26/QB13 (Involvement of business sectors), while 24 out of 39 respondents strongly agreed to QA28/QB15 (Cooperation of various stakeholders from different sectors).

Overall, 97.44% of all respondents acknowledge plastic pollution as societal issue (Q6). Responses to questionnaire A show that, for Q7 (Suitability of RwLs to solve societal issues), 45.5% of public sector respondents agreed, while 50% were neutral. Among private sector respondents, 54.6% agreed. For QA9 (Shared problem understanding), 63.2% of public sector respondents agreed, while 25% of private sector respondents somewhat disagreed, and 75% were neutral. For QA12 (Long-term benefit for organisation), 38.9% of public sector respondents agreed,

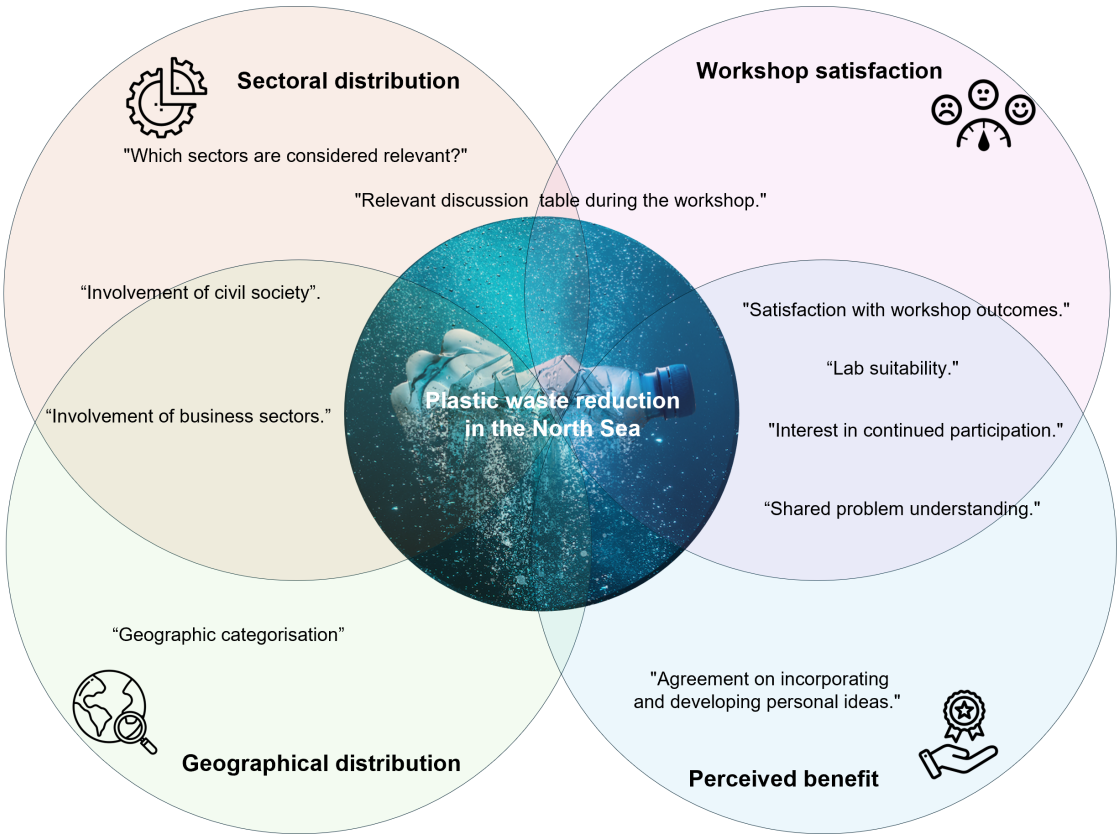

Fig. 4: Clusters of variables in the PCA dimensions, highlighting connections between workshop satisfaction, perceived organisational benefits, and sectoral/geographical distributions. Most influential variables within Dim1 and Dim2 are listed. Overlaps represent interrelationships. The central goal, reduction of plastic outflow into the North Sea, connects these thematic areas.

compared to 25% of private sector respondents. Following suggestions for improvement were made: defining tasks and expectations of participants more clearly, stringent discussion management, observing time, stricter monitoring, and implementation of approached ideas. General reasons for dissatisfaction regarding the overall workshop outcomes were among others: unclear overall concept and goal of the workshop, incomplete documentation and discussion of results, general lack of time, as well as a partly unprofessional moderation. Main reasons to drop out of the RwL-process are: lack of time, finger-pointing against private sector, if implementation is being delegated too heavily to volunteers and does not remain with actors who have time and decision-making power, followed by the fact that the RwL is too theoretical or abstract. The missing leadership from the project research team and the transfer of responsibility to the practitioners by the project management team were also criticised several times. The observation confirmed the stakeholders' unwillingness to take on more responsibility or a leading role during the process. The lack of thematic links to their own work and the fact that other key stakeholders were perceived to show a lack of interest in participation during the process were named as further reasons to drop out of the process.

5 Discussion

This study investigated how the sectoral composition of practice partners and their motivation affects the implementation of RwLs, as part of the regional RwL 'Plastic-FREE-sia', in order to provide general recommendations for the design and early implementation phases of future RwLs.

5.1 Sectoral composition of stakeholders

Scientists and practitioners frequently encounter similar challenges when initiating the research process, as diverse interests of multiple stakeholders

must be balanced in the context of complex transformation processes (Kanning et al. 2021). Our selection of practice partners and their associated stakeholder groups are largely in line with recommendations of RwL and transdisciplinary research literature (e.g. Schäpke et al. 2017). The consensus among several scientists underpinned the selection of practice partners for the transdisciplinary cooperation and the deployment of the RwL 'Plastic-FREE-sia' (see Lang et al. 2012, Beecroft 2018, Eckart et al. 2018, Wanner et al. 2018, Behrens & Keil 2019, Franke et al. 2023). Ensuring the inclusion of a sufficient quantity and broad diversity of stakeholders was critical to the RwL-process (Arnold & Piontek 2018, Singer-Brodowski et al. 2018). According to Lang et al., it "requires the selection of a sufficient number and diversity of stakeholders with a legitimate stake in the process, be it, for instance, because they are negatively affected by the problem or because they are responsible parties" (2012: 36). Our study supports the scientific consensus that a diverse range of practitioners should be involved, as stakeholders emphasised their preference for a broad stakeholder setting from different sectors and indicated that sector-specific collaboration was not a primary concern. Our analysis highlights interrelated patterns among variables, emphasising the nuanced dynamics of workshop evaluation and sectoral perceptions. The moderate positive correlation between QA17 (Equality among participants) and QA26 (Involvement of business sectors) suggests that stakeholders perceiving equality among participants also associate this equality with inclusive sectoral representation. Similarly, the moderate positive correlation between QA26 and Q2 (Importance of plastic pollution in professional or voluntary work) indicates that participants who perceive plastic pollution as critical in their professional or voluntary work are more likely to value the involvement of various sectors. Moreover, our observation suggests that while stakeholders are well-informed about initiatives and organisations within their own sector, they tend to be less aware of initiatives beyond their sectoral scope, highlighting the importance of a diverse stakeholder setting. The weaker correlation between QA8.10 (Involvement of Nature Protection in RwLs) and QA26 reflects a less pronounced but still present connection between identifying specific relevant sectors and the broader inclusion of sectors in addressing plastic pollution. This result may imply that while participants recognise certain sectors as relevant, this recognition does not strongly align with broader sectoral inclusion perceptions. The involvement of stakeholders from own sector (QA24) and the suitability of RwLs to solve societal issues (Q7) was negatively correlated, suggesting that participants believe that a collaborative effort across multiple sectors is essential for addressing societal issues through RwLs. The private sector seemed reluctant to contribute to the debate about the effectiveness of the RwLs in addressing societal challenges, which may be related to their underrepresentation at the stakeholder meeting and due to finger-pointing by public sector actors. Overall, the stakeholder composition, including an underrepresentation of private sector within the RwL 'Plastic-FREE-sia', does not seem to have been a hindrance to the RwL-process.

5.2 Stakeholder motivation

In addition to the composition of stakeholders, the question of stakeholder motivation is also of crucial importance for the implementation of RwLs. The high correlation between Q7 (Lab suitability for societal issues) and QA12 (Long-term benefit for organisation) highlights the importance of perceived relevance. Participants who find the RwL format suitable for addressing societal issues, such as plastic pollution, are also more likely to perceive long-term organisational benefits through their participation. Additionally, the moderate positive correlation between QA12 and QA20 (Satisfaction with workshop outcomes) indicates a direct relationship between satisfaction and perceived benefits. Participants who report high satisfaction with workshop outcomes are also likely to perceive long-term advantages for their organisations, linking immediate satisfaction to broader organisational impacts. Practitioners primarily focus on the direct benefits of the RwL rather than the more abstract contribution to sustainable development (Rose et al. 2019). It can therefore be assumed that some participants left the process when they perceived no benefit for their organisation, whereas some did not see any long-term benefit but are still open to the process. Interests, benefits, objectives, roles, and expectations of all involved stakeholders should therefore be clarified as early as possible (Rose et al. 2017, Eckart et al. 2018, Hilger et al. 2018, Pregernig et al. 2018, Scholl et al. 2018, Siebenhüner 2018, Ober et al. 2019). In general, participants criticised the lack of time and moderation skills, especially during the knowledge production phase as part of the world café format. This criticism can be part-

ly explained by the fact that in RwLs, the research team often has to manage numerous tasks simultaneously. In some cases, these roles range from process organisation, moderation, and observation to advising and implementing interventions (Pohl et al. 2010, Wittmayer & Schäpke 2014, Wagner & Grunwald 2015). The co-design phase of our RwL approach aimed to empower practitioners by taking responsibility for real-world experiments. This was criticised and, in return, a long-term involvement of political decision-makers and scientific actors was desired. In addition, the aspiration to work on a thematically concrete defined framework and the frequently mentioned lack of time capacities can also lead to the situation that actors do not want to take a leading role in the project (e.g. missing leadership from the project research team and the transfer of responsibility to stakeholders was criticised several times). Literature recommends externalising activities that are less related to specific research activities (Wiek 2007, Schauppenlehner-Kloyber & Penker 2015). Other RwLs have established specific roles for coordination and steering (Rose et al. 2017). The higher the importance of plastic pollution in professional or voluntary work (Q2), the more important is the involvement of business sectors (QA26) and therefore, the higher the equality among participants (QA17) was considered to be. This may be due to the fact that stakeholders involved are already aware of the transdisciplinary setting of the RwL. They may already have experience or are receptive to collaborative and participatory approaches. The underrepresentation of the private sector during the regional stakeholder meeting highlights once more the need for an equal representation of various sectors as key prerequisite for the successful implementation of RwLs (Engels & Rogge 2018, Renn 2018, Schneidewind et al. 2018, Singer-Brodowski et al. 2018). The transformative changes needed in plastic production and processing, which necessitate industry involvement, may explain the heightened interest in engaging business stakeholders in the RwL-process.

5.3 Recommendations for future real-world laboratories

Since global plastic pollution presents a complex socio-ecological problem, it should be addressed transdisciplinary and transnationally, in order to develop effective solutions (Holzer et al. 2018, Horton et al. 2025). RwLs have emerged as science-practice interaction approach for the production of robust knowledge to solve real-world environmental and societal challenges (Luederitz et al. 2017). However, our experiences show that the successful implementation of RwLs to tackle large-scale socio-ecological problems, can be challenging. This might be due to the fact that RwLs are rooted in small-scale urban planning and transformative design within cities (Hossain et al. 2019). While it is a promising instrument, it appears to be highly dependent on the scale of the socio-ecological problem it is aiming to address. Based on our experiences within the RwL 'Plastic-FREE-sia' and the results outlined above, we propose recommendations for the design and early implementation phases of future RwLs as outlined in Fig. 5.

We experienced that if the scope - both geographical and thematic scope - is too large or complex, actors lose motivation to participate and the sense of individual responsibility to actively engage in the RwL-process. Similar to the project 'Knowledge creates living space' (see Franke et al. 2023), we omitted the predefinition of specific objectives to allow for an unobstructed co-design phase, which was criticised by survey participants. This deliberate open process paired with the already complex and large-scale nature of the problem setting within the 'TREASURE' project (four thematic project dimensions), hindered the creation of meaningful and lasting engagement of participants. Therefore, we suggest to break down broad goals within socio-ecological problem settings into more manageable dimensions, each with their own objectives. As described by Defila & Di Giulio (2019: 3), RwLs address three objectives: the production of new findings/new knowledge (research objectives), the initiation of transformation processes (practical objectives) and the support of individual and collective learning processes (educational objectives). All objectives should be therefore covered within each dimension and thus, the co-design phase, and all subsequent phases as outlined above, should be also carried out in each of these (Fig. 5).

Within each dimension, key stakeholders should be identified from the outset based on an equal heterogenous representation between all relevant areas of research and practice, as stressed within transdisciplinary literature (e.g. Lang et al. 2012, Pohl et al. 2017, Horton et al. 2025). Since RwLs consist of transdisciplinary cooperation between actors from science, politics, business, administration, and civil society (Schäpke et al. 2017), building up a robust transdisciplinary team along the RwL co-de-

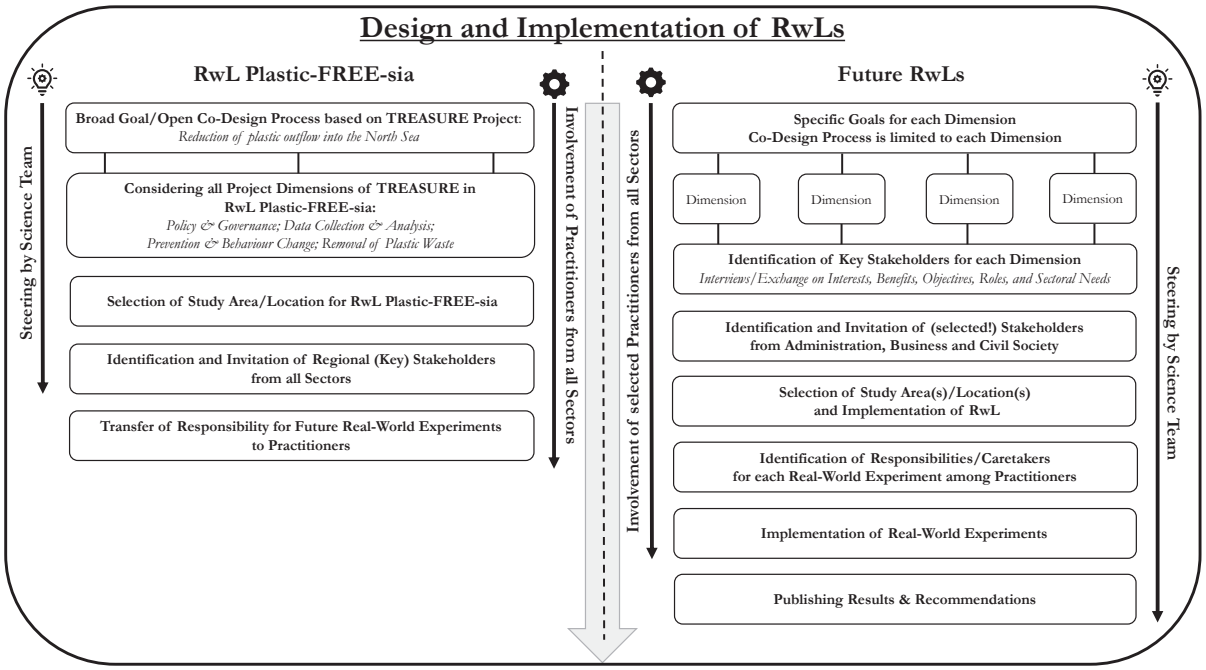

Fig. 5: Comparison between the design and early implementation phases of the regional RwL 'Plastic-FREE-sia' and of recommendations for future RwLs based on our findings

sign phase is fundamental. Our results suggest that commitment and active engagement is fostered, if stakeholders perceive direct or indirect benefits for themselves or their organisation through involvement in the RwL. In order to maintain high levels of motivation among actors, we therefore recommend to clearly identify the involved stakeholders' benefits, and to align objectives, roles, and sectoral needs with their interest as early as possible (Fig. 5).

Due to the complexity of the socio-ecologic problem which is addressed in our RwL, defining a manageable geographical scope in which participants can co-create, co-produce and co-evaluate effective solutions might be a challenge. Ultimately, it depends on the thematic focus of each dimension. Therefore, we suggest identifying key stakeholders first, after which a concrete and targeted study area can be jointly co-defined by the carefully selected stakeholders within each dimension. In terms of the spatial scope, it yet remains unclear to which extent it influences the implementation of a RwL (Rose et al. 2019). Based on our experience, we strongly advise to keep the spatial scope in a manageable perimeter and adapt it to each dimension. Hence, we argue that the geographical scope is highly dependent on the specific objectives of each dimension, as sector representation varies between location, and should preferably be selected after identifying key stakeholders. Thus, the identification of 'caretakers' – participants who would assume decisive leadership and responsibility for the implementation of real-world experiments – must be considered when selecting stakeholders, if the overall RwL-process is expected to outlast the project duration (Fig. 5).

RwLs as an instrument within transdisciplinary research might not guarantee to foster a socio-ecological transformation for large-scale problems but they can create incentives. RwLs show the potential to co-produce small and local solutions that can be scaled up or taken up by future adopters – for example municipalities outside the RwL scope - to possibly achieve a larger impact over a longer period of time. Under those circumstances, RwLs show great potential for tackling large-scale socio-ecological problems of our time, and should be adopted for future projects. For that reason, the 'TREASURE' project is planning on utilising the transnational cooperation to synthesise the experiences and results from all five project regions in Belgium, Denmark, France, Germany and the Netherlands, in order to develop a RwL 'blueprint' that allows future adopters to build on the lessons-learnt and implement real-world experiments to develop long-lasting solutions for the reduction of plastic outflow into the North Sea.

5.4 Study limitations

The collected data represents the specific context of our regional stakeholder meeting and may not be fully applicable to other RwL settings. Moreover, not all stakeholders participated in our survey, which means that the opinions of certain sectors are not represented in our results. Regarding our RwL itself, this study has only focused on the design and the early implementation phases, and recommendations therefore only comprise the initiation of RwLs. Consequently, the proposed recommendations have a limited scope and cannot be applied to the entire RwL-process. The imbalanced participation of stakeholders from the private sector compared to actors from administration & politics and from the civil society during the inaugural regional stakeholder meeting, potentially caused an underrepresentation of industry sectors. A stakeholder mapping could have been carried out, in order to select the most suitable group of targeted and motivated actors. For the purpose of this study, attention was paid to a broad rather than targeted delineation of stakeholders, which could be improved for future RwLs and related projects. Further, it remains unknown to what extent the answers of stakeholders were representing their sector or rather their personal opinions. This was particularly difficult for the administration & politics group, as we engaged with various stakeholders from a wide range of departments within authorities. Our sample was relatively small, and it would have been desirable if even more stakeholders had taken part in the survey, especially in the context of questionnaire B. The small sample size also influenced the statistical analysis and its interpretive strength, with larger sample sizes and feedback from more participants generally yielding more reliable results. More informative statistical methods, such as generalised linear models, could not be implemented due to the small sample size, as the results would likely have been inaccurate. Therefore, robust methods such as factor reduction and correlation analysis were implemented. Furthermore, the questionnaires were not validated prior to their utilisation, which may have impacted their clarity and suitability. Nevertheless, we believe that our findings reflect a general consensus among the participants and could offer insights to enhance RwLs in socio-ecological problem settings.

6 Conclusion

For the first time in the North Sea Region, we have applied the RwL approach to develop solutions for the reduction of plastic outflow into the marine environment. We evaluated the inaugural regional stakeholder meeting of the RwL 'Plastic-FREEsia', so as to formulate recommendations for future RwLs on success factors for the design and early implementation phases of RwLs in socio-ecological problem settings. Our findings indicate that involving diverse stakeholders from multiple sectors in the RwL-process is crucial. This is particularly important when the overall goal is too broad and requires further development, as in the 'TREASURE' project, where practitioners intended to develop real-world experiments across the dimensions of 'governance & policy', 'prevention & behaviour change', 'data collection & analysis', and 'removal of plastic waste'. It is important to strive for a balanced representation between actors in administration, business, civil society, politics, and science, in order to achieve equality among participants. We experienced that if the scope, both geographical and thematic, is too large or complex, actors lose motivation to participate and the sense of individual responsibility to actively engage in the RwL-process. Therefore, we suggest to break down broad goals within socio-ecological problem settings into more manageable dimensions, each with their own objectives. Thus, the co-design phase, and all subsequent phases of the RwL, should be carried out within each dimension, and key stakeholders should be identified from the outset, based on an equal heterogenous representation between all relevant areas of research and practice. To maintain high levels of motivation among actors, we recommend to clearly identify the involved stakeholders' benefits, and to align objectives, roles and sectoral needs with their interest as early as possible. Potentially, this could lead to a more meaningful involvement of key stakeholders and subsequently to a stronger motivation for participation. Conflicting objectives of individual stakeholders should be recognised to a greater extent. To overcome this challenge, it is essential to clarify roles within the transdisciplinary team from the beginning. The identification of 'caretakers', participants who would assume decisive leadership and responsibility for the implementation of real-world experiments, must be considered when selecting stakeholders, if the overall RwL-process is expected to outlast the project duration. Even if it remains unknown how the spatial scope of a RwL may impact its implementation, a large study area can hinder collaboration. Hence, smaller and more manageable perimeters might be more favourable in fostering meaningful cooperation. Our study has shown that our RwL was thematically too broad and the overall

topic is too challenging to address it in one single project. While transdisciplinary collaboration is essential for solving the socio-ecological problems of our time, applying a RwL approach might be challenging in such broad context and therefore not be the best possible approach for the thematic scope of the 'TREASURE' project. However, the potential of RwLs to develop long-lasting solutions within socio-ecological problem settings is evident and following the study's proposed recommendations could possibly further support the effectiveness of RwLs to contribute to meaningful and long-lasting solutions.

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