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Partnership for Risk Reduction

ENHANCE

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Title	REPORT AND DATABASE: RISK ASSESSMENT RESULTS
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SEVENTH FRAMEWORK PROGRAMME

Executive summary

The research area of the Wadden Sea Region (WSR) is characterized as a multi-hazard area. Risk identification in the WSR was undertaken together with representatives from different sectors of all three countries coming together in the Wadden Sea Forum (WSF). The discussion with stakeholders made clear that risks are closely linked to each other and cannot be considered in isolation. Natural hazards in the area, and in particular storm surges, represented the starting point of the discussion facilitated by ENHANCE. Storm surges remained relevant throughout the collaborative process although effective management of the causes of storm surge risks is in place. Other than the risks resulting from storm surges, stakeholders highlighted risks related to environmental changes, the imbalance between economic, ecological and social interests, as well as risks related to demographic change.

The participatory work with stakeholders in the WSR demonstrated that dealing with risks involves more than the simple quantitative process of identifying, quantifying, or monetarily assessing risks and their potential impacts on society. Risk management is a societal process which takes place within a particular socio-cultural context. This context is constantly evolving, and there is constant need for negotiation and mediation between different interests and options. We propose the concept of Integrated Risk Management as a way of targeting this non-linear and dynamic complex system. Integrated Risk Management understands risk management as a continuous process, comprising risk perception and awareness on the one hand and the elements connected to the risk management cycle on the other (risk analysis, risk assessment, risk evaluation, establishment of strategies and measures, risk monitoring). All of these elements are interconnected and embedded in a societal frame. As a successful social process, Integrated Risk Management requires the support of society, different sectors and stakeholders. This in turn requires multi-stakeholder involvement by multiple sectors, firstly for reasons of democratic legitimacy but secondly also because risk management takes place within a non-linear and dynamic complex system. Unless it considers single actors and their interactions at the local (or micro) level, risk management will not be able to handle the resulting emergences and surprises at the regional and national (or macro) level. Risk management therefore has to be understood as a negotiation-based process of governance which addresses needs, objectives and goals, mediates between different interests and, if necessary, rearranges responsibilities so that commonly accepted level of safety can be met. The risk governance perspective draws attention to the diversity of actors involved in risk management, the diversity of their roles, their logic of action, the manifold relationships between them and the range of dynamic networks emerging from these relationships.

ENHANCE has an overall focus on stakeholder collaboration in Multi-Sector-Partnerships (MSPs) in order to enhance risk management of disastrous natural hazards. Case Study 3 focused on the WSR, with the aim of initiating new thinking with respect to integrated risk management in the WSR. Case Study 3 is a collaborative process, involving the stakeholders and institutions represented in an MSP (the Wadden Sea Forum) and acknowledging their role as multipliers in the public, private and civil sector. It is in this context that the

Integrative Risk Management approach was applied in practice. In the WSR, the approach guides the work towards improved risk management.

Risk assessment was conducted as a collaborative, participatory process with the stakeholders involved in the MSP. Risk assessment is a central element of the Integrative Risk Management approach, defined as the process of identifying and evaluating the form, intensity, and impact of risks in a certain area. As such, it is crucial for the development of an appropriate risk management strategy. Risk assessment is more that modeling future developments or estimating the economic costs of the impacts of natural disasters. For the WSR, risk assessment is based on evaluating and assessing possible risks through four quantitative and qualitative approaches. The first is modeling approaches from the natural sciences which focus on climate change as a cause of storm surge events. The second is cost-benefit analysis to determine the monetary consequences of storm surge events. The third is a stakeholder survey among risk managers and the sectors concerned. The fourth is a bow-tie analysis of the causes, threats and consequences of risks, in order to assess the interlinkages between different risks and select appropriate measures for reducing both causes and potential consequences of risks. Three and four are considered crucial: perception and awareness of threats, management needs and responsibilities are essential in determining society's readiness to engage with any risk management strategy.

Risk assessment in the WSR clearly shows that management of the causes of storm surge risks is restricted to climatic and topographic boundaries. Measures are in place to deal with causes of storm surge risks. These are mainly hard coastal engineering measures and generally work well. However, much bigger challenges arise from the consequences of storm surges. This is already the case under current climate conditions and is likely to increase due to climate change. Consequences occur in different sectors and at different levels, and affect the economy, society and the environment. It became clear that improved (storm surge) risk management in the WSR should focus on the consequences of storm surges if society's capacity to mitigate and successfully decrease the resulting risks is to be enhanced. The governance process of risk management should therefore not begin at the impact stage but with an initial identification of risks as a participatory process involving decision-makers, stakeholders and wider society.

The MSP benefits from the results of the risk assessment in terms of increased awareness in the WSR of risk management not only as a technical but a social negotiation process. There is awareness of stakeholder concerns with respect to the consequences of storm surges, gaps in current storm surge risk management, and current and targeted active involvement in storm surge risk management. These set the scene for further negotiation processes and the development of improved strategies, measures or processes to rethink storm surge risk management along the Wadden Sea coast. A basis has been created for an MSP in the form of a permanent stakeholder forum tasked with dealing with risk assessment in the WSR.

Contents

1 Introduction

Whether a natural hazard results in a societal disaster depends on the preventative action of the population and their capacity to react in and recover from crisis situations. Vulnerability, societal resilience and a potential natural disaster are closely connected. Traditionally, structural protection measures have been the response to natural hazards and the resulting risks. In the Wadden Sea Region (WSR) hard engineering measures such as a linear dyke system have provided the main means of defence against storm surges along the coast. However, based on partially devastating experiences, this rather narrow approach has been expanded into more comprehensive risk management in recent years (see EU Flood Directive 2007/60/EC). Along with classic and still important engineering and warning measures (dykes, sand nourishments, retention zones, early warning alerts etc.) there is now a variety of possibilities to reduce damage and harm and to handle risks in hazardous areas (DKKV 2003). Each risk situation demands a thoughtful combination of different measures in order to prevent harm in the community concerned. The question is how the cost-benefit ratio of different measures can be assessed and compared.

Risk is a social construct and needs to be set apart from the concepts of threat or hazard event. In some instances, risk is understood as an algorithmic calculation of "risk = threat x vulnerability x cost". In this equation, threat is understood as the frequency of potentially adverse events, and vulnerability as the likelihood of occurrence. Risk, however, is not a mathematical calculation, but a concept which emerges within societal frames. Risk is bounded and influenced by perception, interests and political will. In consequence, risk management is not only a technical issue, but also takes place within a societal frame, with constantly changing and uncertain boundary conditions. Today's decisions intend to have long term effects, but there is no exact knowledge on how the natural system's dynamic might change due to climate change, or how the social system might change due to demography, changing ways of life, settlement patterns or economic developments. Above all, though, current risk management takes place in historical and cultural settings. If participation and societal support in risk management are understood as crucial, these settings must be taken into consideration. For example, what historic experiences with respect to risks exist in a particular area/society? How have crisis situations traditionally been handled? What risks is society prepared to take? What consequences is society prepared to deal with? What risks are perceived as priority risks and identified as action points for risk management?

These questions are central for the targeted assessment of risk. They will be addressed in the following report. But what does **risk assessment** mean in comparison to **risk management**?
Risk management is a colourful term which is often misunderstood and rarely clearly defined. *Management* means 'to handle' or 'deal with', and comprises more than the simple quantitative process of identifying, quantifying, or monetarily assessing risks and their potential consequences or impacts on society.

Risk management is more than the establishment and monitoring of technical measures to reduce the impact of risk, or the harm to society caused by their consequences.

Risk management, in our understanding, is *a societal process* which addresses uncertainties in relation to society's concerns.

Risk management supports the development of plans, strategies and actions to prevent the causes of risks and to mitigate the consequences of risks in order to reduce their impacts to a commonly acceptable level.

In our understanding, risk management comprises all elements of the risk management cycle (risk analysis, risk assessment, risk evaluation, establishment of strategies and measures, risk evaluation and monitoring). Importantly, however, it also considers the societal framing of risks within which management takes place.

Risk management therefore comprises the actual threats, their causes, and the consequences which demand action at different societal levels and by different sectors and stakeholders.
In consequence, risk management has to be understood as a negotiation-based governance process. Risk management is also understood to mediate between different interests and, if necessary, rearrange responsibilities in order to reach a commonly accepted level of safety. Risk governance is an opportunity to achieve a comprehensive understanding of the WSR as a system. This perspective draws attention to the diversity of actors involved risk management, the diversity of their roles and logic of action, the manifold relationships between them and all kinds of dynamic networks emerging from these relationships (Renn et al. 2011 p.232). Figure 1 sums up the principles in risk management mentioned above.

Risk Management:

- ≠ creating security
- = addresses uncertainties with respect to concerns
- ≥ developing a plan suitable for all instances
- = develops guidance suitable for addressing priority concerns
- ≥ technical measures in the management of the risks
- = flexible/adaptable *handling* of uncertainties
- = a governance process

Figure 1Risk management principles

Against this background, an **Integrated Risk Management** approach is put forward for discussion. Integration is needed of different regional understandings and perceptions of risks. This includes awareness of the linkages between different or multiple risks, of the need for risk impact assessment beyond the monetary realm, as well as understanding of the mental lock-in against new alternative risk handling measures. "Integrated" also means integration of different sectoral and societal interests since risk management is not only a technical plan or measure installed top down but a societal negotiation process involving multiple stakeholders, the public and administration. Taking into account the characteristics of governance processes, integrated risk management emphasises the restrictions imposed by societal frames and the possibilities of embedding newly developed decision processes in existing political and social structures.

The focus of this report is on the assessment of risk as part of an integrated risk management approach. A step which precedes the step of risk assessment is risk analysis, which helps to identify the risks in terms of vulnerabilities in the light of existing or planned future drivers operating in the management area (including changing environmental conditions). Risk assessment in the case study WSR therefore includes the identification and analysis of the hazard situation (see Chapter 3.1, 3.2) as well as the identification of the scale at which the risks will be addressed and where responsibilities are located (see Chapter 3.3).

Since uncertainty with regard to future development cannot be addressed by more precise projection modelling alone, we apply three methods for assessing the impacts of risks. Causes and consequences of threats will be assessed as scenarios, as a perception study, and as a result of a discussion process with Wadden Sea stakeholders. Risk assessment also has to take into consideration the societal framing within which risk management takes place. Therefore, an understanding of the social system is necessary, which is addressed in the empirical part of our case study. The three methods of risk assessment are employed in order to understand the variety of aspects involved, as well as the varied perspectives and competing interests which play a role when developing protection or prevention schemes. For the WSR, risk assessment addresses the following questions:

Which risks are identified as crucial in the WSR?

Is there a common understanding of risks across the national divide?

How should causes and consequences be specified or distinguished from each other?

Who is currently responsible for risk management?

Can we learn from each other in the trilateral WSR?

Is there readiness for a cooperative, trilateral approach?

1.1 Summary of the type of risks in the trilateral Wadden Sea Region

The Wadden Sea coast has been a highly vulnerable natural area since human settlement began there in 1575-1200 BC (Wadden Academy 2013). Over the centuries this low-lying, tidal coastal region along the Dutch, German and Danish North Sea coast has experienced numerous profound transformative processes, some driven by natural forces and others by human activity. As a result of these processes, the WSR and its population has always been at risk since settlement and farming began and intensified in the late Bronze Age (Lotze et al. 2005, Knottnerus 2005). Dealing with these risks has always played an important role in the coastal communities along the Wadden Sea coast. This particularly applies to risks arising from natural hazards, and communities in the WSR look back on a long tradition of living with and handling these risks. To this day, storm surges have posed a major threat to the region and its society more than any other natural hazard. In order to protect settlements and agricultural land against flooding and damage due to storm surge events, as well as the effect of rising sea levels, protective structures (dwelling mounds, ring dykes, closed dyke lines) have been installed along the coast since the beginning of the 10th century (Oost et al. 2012, Wadden Academy 2013) and have been continuously improved. As a result of the success of these protective measures, the region experienced considerable population growth and accretion of goods and values. This in turn lead to a steady growth of vulnerability. Even today, where dykes and other coastal protection facilities are built to high safety standards, residual risks still remain – no structure can ensure total safety.

However, the WSR is not only threatened by storm surges. Recently it has developed into a multi-risk area, where multiple risks result from different natural hazards and socio-economic developments. Apart from storm surges, there is a risk of heavy storms and heavy rainfall events. The former can cause damage to buildings, infrastructure as well as increased indirect losses for the regional economy, whilst the latter can lead to flooding events and pose a challenge to the WSR due to insufficient drainage of the hinterland. As a result of dyke construction and increased drainage of the lower-lying marshland, the land behind the dykes continuously subsides, in many regions below sea level. If, during a heavy rainfall event, there are sudden high rates of river runoff, these water masses will accumulate in the low lying areas, leading to increasingly wet soil and the need to pump out water which is technically challenging and expensive.

In the future, climate change will affect the WSR through changes in climate parameters. Especially sea level rise, which has altered the coastline for centuries (Behre 2004; CPSL 2010; Church et al. 2001), will most probably accelerate due to climate change (global sea level: IPCC 2013, for local sea level rise: Katsman et al. 2011). Increased water levels resulting from sea level rise will increase the difficulties of coastal protection due to a positive feedback on storm surge water levels (Worth et al. 2006).

Beyond the risks resulting from natural hazards, the WSR is also exposed to risks resulting from socio-demographic change. For the past decade[1], a population decline can be observed in most of the region's municipalities[2] combined with a relatively small and still declining share of young inhabitants[3]. At the same time, the share of older inhabitants in relation to the total population has increased (2003-2011) in the whole WSR. In addition, the WSR faces changes and risks to the regional economy and, specific to the ecosystem, a loss of biodiversity and the invasion of alien species.

The multitude of risks and the uncertainties with regards to their consequences for the region’s population, represent a highly interlinked risk system in the WSR. Many of the above

[1] Years 2002, 2009-2011 are evaluated
[2] Available data for specific research area from WSF
[3] 15-24 years, compared to the total national population, data from 2003-2011, Source WSF, based on Statistics Denmark, Statistics Netherlands, Regionaldatenbank Germany

risks are related to each other in causal relationships and cascading processes. Under these circumstances, risk management becomes a societal endeavour which must consider people's awareness and perception of risks as well as their prioritization in terms of dealing with these risks. In a multi-dimensional risk situation, technical solutions to single hazards will no longer be enough.

As a starting point, there is need to deconstruct existing perceptions on the predominant risks in the region. Based on this understanding, the necessary action can be taken. Risks are understood here as mental constructs which evolve from individual perception, interpretations of the environment and responses depending on social, political, economic and cultural contexts and judgments (Luhmann 1993). Different cultures have different conceptions of risk based on cognition resulting from personal experience, knowledge, and culturally framed perception (Ratter 2012, 2013). As a consequence, communication and discussion are essential in order to initiate changes in the predominant mental constructs and reframe coastal risk management and engineering-based solutions in favour of more flexible and multi-facetted risk management strategies.

During the first workshop with stakeholders from all three countries represented in the Wadden Sea Forum (WSF), an open discussion was stimulated on risk perception and awareness. The discussion showed that storm surge risks along the Wadden Sea coast are an important issue for almost all institutions and sectors. Most of the stakeholders agreed that the technical measures currently employed against storm surges are working well in the WSR. As a consequence, most agree there is no urgent need for improving current coastal protection strategies in the near future. Only potential changes in storm surge patterns and an increased sea level might increase risks and demand new measures (Gerkensmeier et al. 2014).

An important result of the workshop discussion was the identification of other regional risks that need to be dealt with. For the participating stakeholders, the most important risks are those related to changes in society, especially those connected to demographic change and an ageing society. To stakeholders, a clear priority for improved risk management is therefore to address demographic change. In second place, the WSF identified risks resulting from conflicting spatial uses as action points, followed by threats through shipping and oil tanker accidents, risks resulting from economic crises, and environmental impacts from pollution and emission (Gerkensmeier et al. 2014). Working with stakeholders made clear that not only is the WSR faced with a multitude of risks, but that there is also a need for improved risk management strategies beyond technical storm surge protection. The workshop discussion disclosed the high level of interconnectedness of the different risks, characterized by interlinkages delayed in time and space as well as cascading and surprising effects between different risks. Focusing on only one of these risks would not meet stakeholder expectations and risk management requirements. Based on these insights the case study's approach was broadened and adjusted to the WSF requirements.

The ENHANCE challenge lies in the reframing of risk management, detecting mental lock-ins against alternative approaches and tackling potentials for trilateral cooperation in a multi-risk area. The aim of the Case Study 3 is to initiate new paths of thought with respect to integrated risk management in the WSR together with the stakeholders and institutions represented in the WSF, incorporating their role as multipliers in the public, private and civil sector. The risk situation detected demands multi-dimensional approaches which are broadly supported by multi-sector-partnerships (MSP). Taking into account that communication and discussion are essential for initiating change in mental constructs, reframing coastal risk management, enhanced stakeholder awareness of the cascading effects between different risks, as well as increased awareness of direct and indirect impacts are first steps along the road towards new and integrated ways of dealing with future development. The WSF represents an existing MSP in the WSR. As such, it can foster this rethinking of traditional risk management approaches and the inclusion of different stakeholder responsibilities of different sectors, including the private sector.

1.2 Risk assessment as integral part of risk management

The Wadden Sea case study defines risk management as a societal process – including the societal framing of risk (risk perception, risk awareness), risk analysis, risk assessment and evaluation, establishment of strategies and measures and ongoing risk evaluation and monitoring. The established concept for the Case Study 3 is the **integrative risk management** approach which, in contrast to classic risk management approaches, focuses more on the integration of different sectoral interests and concerns and the influences and restrictions imposed by societal frames. The starting point for adequate integrative risk management is the identification and understanding of risks among the regional population, as this determines the concerns and needs of the people involved in and impacted by the risk management process. The second element in integrated risk management is risk analysis which helps to identify risks from the perspective of vulnerabilities and in the light of existing or future drivers operating in the management area (e.g. climate change). Risk analysis should include analysis of the likelihoods of potential ecosystem and socio-economic impacts in relation to natural events and human activities, taking into account potentially different courses of action. The third element of integrative risk management is risk assessment, which aims to acquire an understanding of the potential consequences and impacts in relation to the perceived risks. These steps are followed by the development of an adequate risk strategy or measures to adapt to the causes of risks and reduce the consequences of risks. The risk management process itself should also include an ongoing evaluation and monitoring process in order to deal with changes and upcoming uncertainties (Ratter 2013). Integrated risk management should ensure that processes are installed to monitor environmental health and the life worlds of people, and to evaluate the success of preparatory, adaptation and emergency measures (see
Figure 2).

In a nutshell**, risk assessment** is understood as part of the social process; as such it is influenced by competing interests and structured by multi-level responsibility. Assessing different potential risk impacts is more than calculating potential economic harm. It includes the evaluation of consequences, taking into account competing interests in different sectors, as well as the evaluation of various courses of action. Last not least, it includes the selection of management action in a cooperative process involving the affected stakeholders and the community which addresses the risks (see the 'cost assessment cycle' a framework for the integrated cost assessment of natural hazards, in Kreibich et al. 2014).

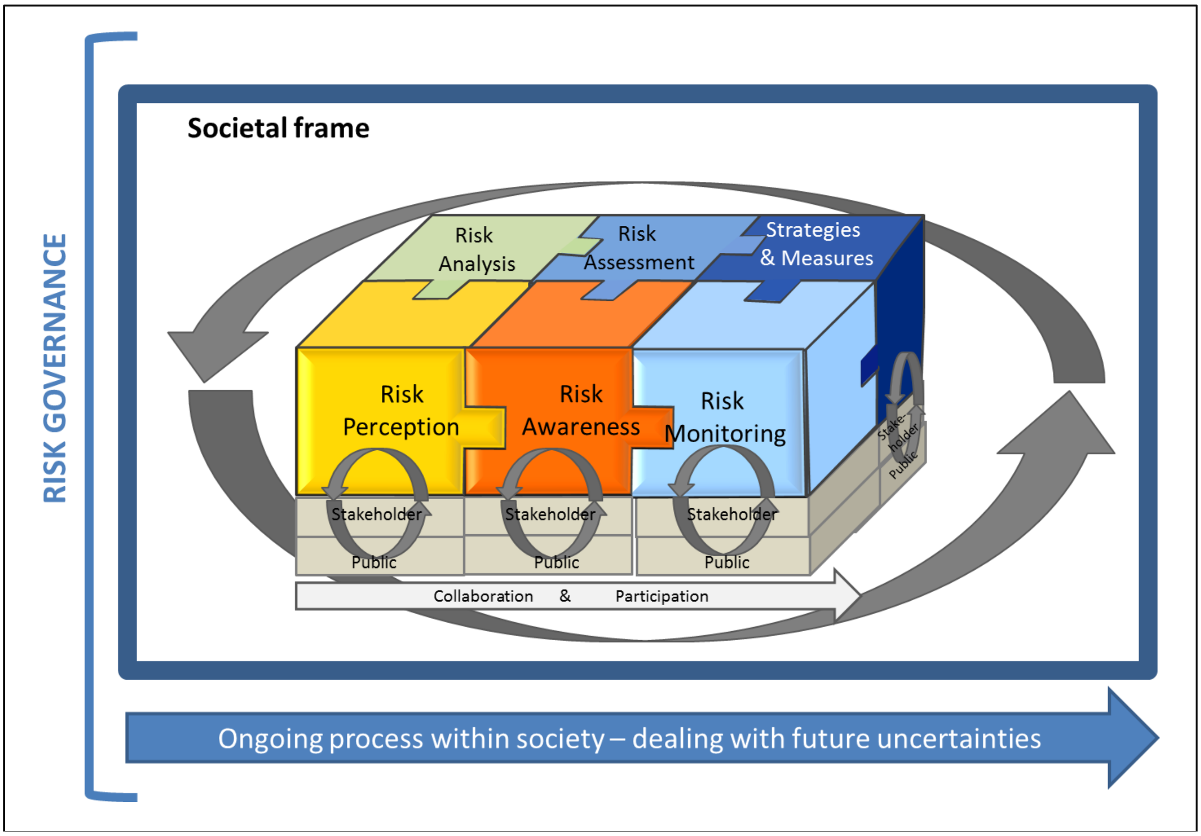

Figure 2 Integrative risk management concept
Dealing with risks requires more than the classic elements of risk management (commonly understood as risk analysis, risk assessment, development of strategies and measures to handle the risks, processes to monitor these elements). Successful risk management considers risk perception and risk awareness as equally important. Fig. 2 shows all of these elements as interlocking pieces of a jigsaw. Risk management takes place within a specific societal frame with constantly changing and uncertain conditions; these in turn influence management processes. Accounting for these aspects requires collaboration between the public and governmental/administrative institutions, as well as participation and societal support from stakeholders and the public at large. It follows that risk management has to be understood as a negotiation-based process of governance which addresses needs, objectives and goals, mediates between different interests and, if necessary, (re-)arranges responsibilities. Risk governance draws attention to the diversity of actors, their roles, their logic of action, the manifold relationships between them and the dynamic networks emerging from these relationships

Based on these general ideas, integrated risk management is comprehensive not only in the sense that all management steps are included in an ongoing process, but also in terms of acknowledging the shared responsibility between all agents of the social system. Integrative risk management in this sense becomes a collaborative process involving the public, the private sector and the public at large. Top down approaches imposed by governments cannot be successful. Without the integration and respect of societal and stakeholder interests, and without facilitating space for negotiation and bargaining the management process will fail.
The performance of risk management processes is affected by the fact that operations happen at multiple levels, that multiple actors are involved in coping with risks and their consequences, that there is individual framing of scale and a that common understanding

and framing of scales within the society affect the risk management processes. From our point of view it is essential to consider these processes as highly important. This approach is not inconsistent with the "classic" steps in risk management (see above). These elements are part of a comprehensive process of dealing with risk; they are also closely linked to and influenced by perception and awareness of risk, as well as participatory and collaborative processes.

Therefore, it is essential to have continuous and close connections to stakeholders and the public during the process**. Collaborative** and **participatory processes** represent a central element in integrative risk management processes in order to ensure a continuous exchange and feedback to current management processes. Communication and discussion between the responsible administrative actors, representatives of different sectors or interest groups (often summed up in the term "stakeholders") and the population are essential in order to continuously adjust risk management processes to the societal frame. The emphasis on cooperative and participative procedures in risk management goes hand-in-hand with different EU legislation which aims at thematic and spatial integration (e.g. EU Flood Directive 2007/60/EC). In general, the integrative risk management approach underlines that stakeholder engagement, if it is performed as a genuine two-way communication, is a tool to increase the effectiveness of risk management.

The following section will introduce the purpose of a Multi-Sector Partnership in coastal risk management in the WSR.

1.3 Purpose of the MSP in risk management

Risk management, both with regard to natural hazards like storm surges and risks caused by misguided social or economic development, is currently organised along the national divide and responsibilities in the Wadden Sea countries. Within the national context, responsibilities for risk management are located at different administrative levels (amongst others as a function of the different administrative systems in the different countries). In addition, risk management structures vary in many cases according the different type of risks.

Based on the general observations and definition of integrated risk management (see above), actual responsibility and engagement in this societal process should be shared between administrative, technical, private and public stakeholders. It is the interaction of agents at the micro level of a society which causes surprising emergences at the macro level (Ratter 2012, 2013). Integration of stakeholders is therefore not only a democratic requirement in a pluralistic society but a pillar for broadly implemented management approaches.

In the WSR we have a special situation of stakeholders, competing interests and involvement. It is the aim of the case study to introduce an enhanced perspective on risk management by including the trilateral level in these processes. One of the starting points for this purpose is awareness of the similarity of problems and risks the Wadden Sea countries have to deal with. Apart from similar geophysical structures, which cause increased vulnerability to natural hazards, similar socio-economic structures in the coastal areas in all three countries have favoured the development of similar problems and risks. The stakeholder dialogue with the representatives in the WSF demonstrated much common understanding, with larger discrepancies between the different sectors than countries. Potentially, improvement in risk management activities can be reached by increased communication and exchange of knowledge as well as potential cross-border, collaborative activities. Encouragement towards such steps is provided by the positive experiences in trilateral cooperation, specifically the long-lasting cooperative activities in nature conservation.

Engaging in collaborative, cross-border processes in risk management requires an overview of different risks and problems as well as representation of different perspectives (e.g. sectors, interest groups) in order to develop strategies that find common acceptance and support in society. Moreover, the broad variety of risks and their interconnectedness demonstrate a need for broad stakeholder involvement as an integrative part of coastal risk management, in order to address future challenges and handle risks according to the needs and concerns of society. Therefore, the case study considers collaboration in form of a MSP an appropriate way of dealing with risk management on a trilateral level.

Against the background of the current situation in coastal risk management, it is the objective of the MSP to introduce initial steps towards a collaborative, cross-sectoral, coastal risk management within the WSR. The aim of the case study is to stimulate a discussion among stakeholders represented in the trilateral WSF. This existing multi-stakeholder group can help to foster growing awareness of the interdependencies of risks and their impacts. It can also start a communication process between all the affected sectors on how to deal with these risks and the resulting uncertainties, especially with regard to future changes (e.g. climate change) in the WSR. The MSP as a multiplier can initiate a snowball effect and inspire other stakeholders to become more open towards a re-thinking of risks and their engagement in risk management. A comprehensive understanding of linear and non-linear (direct or indirect) relationships between different risks and their potential impacts can foster the development of successful coastal risk management strategies in the WSR. The MSP is sensitized to the importance of raising awareness of the variety of risks and their cascading multi-level effects. The main objective is not the development of specific risk management plans, but to provide a basis for practical steps in the form of increased discourse and knowledge about requirements in risk management and acceptance of measures and strategic orientation in risk management strategies.

1.4 Purpose of risk assessment

It is the general aim of CS 3 to initiate new paths of thought about the varieties of risk in the WSR. The project can also foster a growing awareness of new responsibilities for society and stakeholders. As already stated, these processes are part of the integrative risk management approach and are embedded in a societal frame that is influenced by competing interests and structured by multi-level responsibility. Risk assessment is one element in integrative risk management. In our understanding risk assessment includes the evaluation of consequences based on competing interests in different sectors as well as an evaluation of various courses of action and selected management actions in a cooperative process that addresses the risks together with the affected stakeholders.

In terms of assessing risks, it is important to keep in mind that risk assessment not only involves the assessment of hazards or risks from a scientific point of view, but also from the perspective of the society which experiences or lives through the socio-economic impacts of a hazardous event. Quantitative risk assessment helps to analyse potential exposure to the physical effects of a hazard event or risk and to estimate the monetary vulnerability of the community when subjected to the physical effects of the event, taking into account the potential damage to goods, values and human life. These results support decision-makers in setting priorities, in comparing and evaluating different measures and strategies and in deciding which kind of strategy should be implemented.

The main criticism of quantitative risk assessment as presented by Cox (2009) underlines that many quantitative assessment approaches neglect the fact that most people care about "the intent behind an action, the perceived fairness of decisions, the perceived equity of opportunities and outcomes embedded in a decision process and its results, and whether the selected act respects norms of reciprocity and fairness in its allocation of gains and losses (Cox 2009 following Ohmura and Yamagishi, 2005; Sanchez and Cuesta, 2005; Camerer and Fehr, 2006). It becomes clear that risks are constructed and shaped by social and intuitive processes – and that these constructs could deviate from the formal numeric results of quantitative risk assessment processes. Consequently, formal numeric risk assessment methods are not able to represent the intuitive, social judgment of risks. In order to overcome these limits, it is important to focus on the pluralistic rationalities of risk held by different stakeholder groups (e.g. scientists, policy makers, and the public) and civil society. This usually implies a methodological shift towards qualitative rather than quantitative risk assessment.

Qualitative risk assessment, for us, **focuses on stakeholder concerns and rationalities** as well as **processes** between partners. It includes more than the numeric outcomes of specific assessments, e.g. the efficiency of a certain measure. In our case study, the causes and consequences of the perceived threats are assessed by means of scenarios, a perception study, and as a result of a discussion process with our stakeholders. With this approach we are not aiming to replace quantitative steps. Qualitative risk assessment is understood as a complementary approach which focuses on different rationalities and concerns with regard to risks. It is applicable especially in uncertain situations where monetary assessments alone are not sufficient and where the risk situation highly politicized. From a sociological perspective on risks, it is clear that different value judgments and emotional responses which affect the perception of risks and uncertainties have to be included in order to meet the requirement of adequate risk assessment (Cox 2009, Solvic et al. 2004; Klinke & Renn 2002).

In the WSR risks can be more successfully assessed by a combination of quantitative and qualitative methods. Storm surge protection in the WSR is embedded in a highly politicized context. The long-standing tradition of fighting against the sea and dealing with dramatic losses in value and human life has culminated in a symbolic battle of the coastal population against storm surges. Coastal protection today is a culturally highly politicized issue where discussions of safety cannot be separated from existential feelings and arguments. In this context a purely quantitative assessment is inappropriate.

Our approach is the combination of quantitative and qualitative approaches in order to arrive at an adequate integrated risk assessment. We combine three different perspectives from which to assess the impacts of risks to society. Causes and consequences of storms surges are assessed (i) with the help of climate scenarios, flood maps and (ii) a comprehensive state-of-the-art desktop study on storm surge damage modelling and (iii) by means of a perception study carried out through an online survey. A discussion of causes and consequences of multiple risks and their interlinkages with our stakeholders (iv) is supported by a bow-tie analysis. These approaches, and the quantitative assessment of causes and consequences of storm surges they allow, provide the basis for generating more in-depth knowledge and understanding of the risks arising from natural hazards.

Re (i): For storm surge risks, which have been highlighted as an important element of the multi-risk environment of the WSR, future scenarios are available. We analyse these data in order to assess potential future causes that could affect storm surge events.

Re (ii): The consequences of storm surges are assessed based on an inventory of state-of-the-art science on storm surge damage modelling (special focus Germany).

Re (iii): The assessment of storm surge risks is complemented by the first results of a personalized online questionnaire on storm surge risk management in the northern part of the German Wadden Sea coast. These results offer insights on different rationalities in storm surge risk management held by stakeholders from different sectors, all of whom are to some degree in charge of storm surge risk management. Results will guide the work of the MSP in order to meet the needs of the broad Wadden Sea community with respect to risk management.

Re (iv): The integration of socio-economic aspects takes place via the analysis of risk perception, societal processes and responsibilities in current risk management structures. Both topics were discussed with the stakeholder of the MSP in two participatory workshops with the help of a bow-tie analysis.

2 Risk assessment in the Wadden Sea Case Study- *Specification of the analysis*

Risk assessment in the Wadden Sea Region (WSR) includes the identification and investigation of the hazard situation, differentiating between the causes and consequences of the perceived risks and identifying the scales at which risks will be addressed and where respective responsibilities lie. In our understanding, risk assessment not only includes the identification of causes of threats, but also the evaluation of consequences based on competing interests in different sectors. Measures are required to address both of these aspects. Therefore, evaluation of different courses of action is needed in order to select management actions which best address the risks. This should be done in a cooperative process together with the stakeholders.

The case study applied a combination of quantitative and qualitative approaches in risk assessment. The risk assessment approach has been adapted to the situation in the WSR, where the discussion on storm surge protection is embedded in a highly politicized situation. We have to acknowledge that the ENHANCE project is not dealing with a blank canvas or an area where risk management is an alien concept. Based on historic and recent experiences, coastal engineering measures have proven crucial in the protection against storm surge events. Many other regulations are in place which address existing hazards (e.g. for shipping safety, environmental protection, spatial planning etc.). Administrative responsibility in all three countries is well developed and constantly adjusted to actual needs.

Taking into account the cultural history of the region and its long-standing fight against the sea, it is not surprising that safety and security issues are highly symbolically charged. The discourse on coastal protection is widely influenced by emotions, fears, concerns and interests. In this context purely rational and quantitative assessment is inappropriate. Therefore, Case Study 3 assesses the impacts of risks on society through three different lenses. This include a quantitative and qualitative evaluation of the consequences of risks based on competing interests in different sectors, as well as an assessment of various courses of action in a cooperative process together with the stakeholders.

The three perspectives include a) a quantitative assessment of causes and consequences of storm surge risks with the help of existing climate scenarios, flood maps and a state-of-the-art desktop study on storm surge damage modelling; b) a qualitative perception study via an online survey among the experts involved in risk management; and c) a bow-tie analysis of causes and consequences of risks and their interlinkages based on a discussion process with the stakeholders represented in the Wadden Sea Forum (WSF).

The following chapters present a description and evaluation of the three analytical perspectives. The results of the analysis are presented in Chapter 3. Chapter 2.1 is dedicated to the **causes** of risks and presents an overview of existing quantitative climate scenarios and flood maps for the WSR. Chapter 2.2 addresses **consequences** of naturally induced risks and the current risk management process, providing a desktop study of quantitative risk assessment in storm surge damage modelling, followed by a qualitative assessment of current stakeholder involvement in storm surge risk management based on a stakeholder survey. Chapter 2.3 is dedicated to the assessment of **interlinkages** between causes, consequences and the respective risk management measures that are required. In Case Study 3, the bow-tie approach is used as participatory approach to discuss risk assessment with the members of the WSF.

2.1 Assessing causes: Existing climate scenarios and flood maps for the Wadden Sea Region

What are the causes of current and future storm surge hazards along the Wadden Sea coast? The answer is climate conditions as well as current coastal protection measures, since both represent important boundary conditions which cause or influence the occurrence of hazardous storm surge events. In order to assess the causes of storm surge risks, an analysis is presented of existing projections and visions for the future of the WSR.

Climate scenarios

Several risks in the WSR are caused by climatic conditions or are partly dependent on climate parameters. Events like storm surges, heavy rainfall or storm events but also changes in precipitation patterns (dry and wet seasons) and in the vegetation period are closely linked to climate parameters. Changes in these parameters could pose major threats to WSR society, as they could have a major impact on the occurrence of different risk events. Changes in the frequency and amplitude of storm events, for example, could influence potential levels of threat.

Scenarios based on changes in climate parameters in the WSR are available from dynamic and statistical modelling. This information is important for assessing and projecting future risks that could result from storm surges. Moreover, climate parameters such as temperature and precipitation are linked to other risks. An increase in heavy rainfall events, for example, will increase flooding events in the hinterland.

For the German WSR regional climate models are available, delivering different scenarios of potential change. In order to make this scientific information manageable for stakeholders, decision-makers and society, dialogue between scientists, practitioners and society is essential. At the Helmholtz-Zentrum Geesthacht (HZG) the North German Climate Office specializes in facilitating communication between scientists and society by providing information about climate change in Northern Germany and by advising decision makers on how to use regional climate scenarios. Through a cooperative agreement between the WSF and the North German Climate Office, these climate scenarios have been extended to the whole trilateral WSR. The aim of this cooperation is to provide answers to questions of high interest for the WSF stakeholders, including e.g. what sea levels can be expected in the southern North Sea in 2050, how the vegetation period might change over the next decades, and what temperatures can be expected along the coast.

The North German Climate Office has responded to the requirements of the WSF sectors by establishing the so-called coastal atlas[4]; a digital internet atlas that allows users to inform

[4] Available at http://www.coastalatlas.org/

themselves on future climate changes expected in the WSR. At the regional scale[5] the climate atlas offers information on typical climate variables (temperature, precipitation, wind etc.) drawn together from different regional climate scenarios.

The set of regional climate scenarios available for the WSR currently includes 12 different climate scenarios resulting from 4 different regional climate models. 4 climate scenarios were calculated by the COSMO-CLM model (Hollweg et al. 2008) which is a regional climate model run by a community of over 30 international research institutions (Rockel et al. 2008); 3 climate scenarios were calculated by the REMO-UBA model (Jacob et al. 2008) and another one was calculated by the REMO-BFG model. In addition, 4 climate scenarios were calculated by the RCAO model which is a regional climate model of the Swedish weather service SMHI (Döscher et al. 2002). These future climate scenarios are based on greenhouse gas emission scenarios by the IPCC (IPCC 2000). The climate scenario information is offered for thirteen 30-year windows from 2011 to 2100 wherein climate scenario information can be selected for every season. Apart from the information from different scenarios, information is presented on the degree of agreement between the climate scenarios using a colour code. Moreover, the atlas highlights where all climate scenarios project no change of the climate variable, presenting also where projections show different signs. Important variables for the discussion within the ENHANCE project include, amongst others, storm intensity[6], storm days[7] and days with heavy rainfall. Recently, the North German Climate Office analysed climate data of the past 60 years for Northern Germany[8], which highlights the development of climate change measured so far. This analysis also strengthened the basis for the scenarios for the WSR.

Flood maps: reflecting the risks from storm surge events

With regard to storm surge risks, the North German Climate Office provides an additional tool which can potentially support the discussion with stakeholders in the MSP. The online tool[9] "Coastal protection needs" (Küstenschutzbedarf) provides information on coastal protection needs along the German North and Baltic Sea coasts by illustrating potentially flooded areas along the coast based on three different situations. An interactive map allows users to determine which areas are currently protected by coastal defence (using the example of normal high water level and the example of the disastrous storm surge event of 16/17 February 1962). Potential new demands for coastal protection and potentially flooded areas in case of a very high storm surge event[10] are presented up until 2100. This tool specifically addresses the situation in the low-lying coastal areas, with the aim of informing society on areas that could be affected by storm surges in the future. The resolution of this tool is at a very detailed, local level.

[5] The coastal atlas is only available at the transnational, regional scale of the Wadden Sea. Smaller scales are only available for Germany on the Norddeutsche Klimaatlas (http://www.norddeutscher-klimaatlas.de/)
[6] Storms intensity is defined by the maximum absolute value of the wind vector in 10 m height
[7] Storm days are defined as Number of days with a maximum wind speed over 62 km/h (Vmax > 62 km/h)
[8] For more information please see http://www.norddeutscher-klimamonitor.de/
[9] Available at http://www.kuestenschutzbedarf.de/nordsee.html for the German North Sea Coast
[10] An exemplary scenario for a very high storm surge event is given by the scenario of the storm surge water level of February 16/17th 1962 plus 1.1 m. Data source for the coastal atlas: coastDat hindcast and scenario data. For detailed information see the website of the coastal atlas.

The ENHANCE project benefits from this comprehensive overview presented by the North German Climate Office. The material presented and the future scenarios provided are used as basic information and applied in the participatory process with the WSF.

2.2 Assessing consequences: Storm surge risks and the current management process

The most important natural hazard events along the WSR are the risks resulting from storm surges.[11] In order to present a comprehensive risk assessment of consequences resulting from storm surge events, we sought to use two different types of analysis. The first type analysis is about damage modelling, which uses modelling to assess the potential economic damage resulting from storm surge events. This quantitative type of assessment provides estimates of potential monetary damage and losses. Numeric models could reproduce both, the current situation including currently applied coastal protection measures and different future scenarios taking different kind of coastal protection measures into account. Both settings are used to estimate the monetary losses under current and potential future coastal protection schemes. The second type of analysis is a personalized online survey which aimed at assessing the current state of storm surge risk management. This qualitative method is capable of including different perspectives and concerns; as such it allows the assessment of different rationalities and views of partner responsibilities in the risk management process.

2.2.1 Quantitative assessment: storm surge damage modelling

Estimating the impacts and losses arising from a potential hazard event represents an essential element of quantitative risk assessment. Finding an answer to the question, how the cost-benefit ratio for certain measures can be assessed, can be facilitated by the assessment of potential monetary losses in the case of an extreme hazard event. Monetary estimation of losses and damages caused by storm surges along the North Sea coast in general, and especially along the Wadden Sea coast, could provide supportive information with regard to coastal risk management and the development of coastal protection strategies and measures. However, monetary assessment of storm surge damage is a sensitive and highly political issue in the area. In general, management of storm surges in all three countries focuses on prevention and is an issue of high priority especially in the WSR of the Netherlands and Germany. This priorisation becomes apparent on closer inspection of the responsibilities and funding mechanisms, which finds a dominant, supervisory position of national and regional governments. In all three countries, responsibility for coastal protection issues predominantly lies in the hands of ministries on national or regional/federal levels (Mulder et al. 2011; TAW 2002; NLWKN 2007; MELUR 2013; Kystdirektoratet 2012). As a consequence of the disastrous storm surge events of 1953 and 1962, the Netherlands, and Germany in particular implemented improved coastal protection strategies and strengthened their administrative structures.

Responsibility for coastal protection has shifted from being a task of residents in the low-lying areas (who directly benefit from protection measures) to a task of governmental institutions (for a detailed description see Gerkensmeier et al. 2013). This shift was

11 This was confirmed by the stakeholders of the MSP in the first participatory workshop with the WSF.

accompanied by a certain alienation of coastal residents, expressed in their reduced involvement in coastal protection and generally lower awareness of coastal protection measures. In line with this shift, current storm surge management is dominated by governmental actors[12], where decision-making processes are organized in hierarchical top-down fashion.

Although coastal protection is of high priority in all Wadden Sea countries, different attitudes exist towards dealing with risks as well as potential residual risks. Differences in safety standards alone complicate consideration of the WSR as a single unit. Different risk cultures are apparent in different protection strategies, different standards of protection, and different mentalities with respect to coastal protection. Under these circumstances, general cross-national damage assessment is not only difficult, but near enough impossible for the area as a whole. The politically sensitive nature of the topic is also reflected in scientific research and storm surge impact modelling for the North Sea Region.[13] Large scale assessment of storm surge impacts and especially projection of monetary losses can cause discomfort among the people concerned and may have political ramifications. Slipshod projections have to be avoided. Estimates of damages and losses have to be carefully performed, and in the interest of coastal residents false alarms should be avoided. Attention must also be paid to the spatial resolution at which such estimates are calculated, as well as certain diversity in the categories in which damages are assessed. Responsible and considerate handling of information and dissemination of results is needed. Chapter 3.1 compares the results of existing studies of this kind.

2.2.2 Qualitative assessment: stakeholder involvement in storm surge risk management

Consideration of different rationalities and concerns of different institutions, sectors and the public plays an important role in successful risk assessment in the WSR. Cultural roots, social perceptions and behaviour have to be taken into account as these are essential elements in this process. With the support of the Environmental Hydraulics Institute, University of Cantabria, Spain, (EHIUC), we applied a special qualitative approach designed to assess the resilience of a community based on understanding institutional, legal and social capacities for coping and recovering from a natural hazardous event.

Based on experiences in other countries, the EHIUC developed a survey-based concept to explore stakeholder perceptions of risk and emergency management processes as well as psychological and social factors conditioning individual and community preparedness (González-Riancho et al. 2015). In Case Study 3, this concept was applied to storm surge risk management, its perception and the resilience capacity of risk management personnel.

[12] Governmental actors include ministries, state agencies, counties, provinces and municipalities as well as and water boards and dyke associations. Dyke associations are the German version of Dutch water boards with a comparable organization structure and responsibility in all three Wadden Sea states along the North Sea coast (NLWKN 2007). The current state of the German dyke associations is related to a long historic development; its original structures predominantly results from loose forms of loose interest groups and village communities.

[13] A comprehensive desktop study was performed in Case Study 3. It will be presented in detail in Chapter 3.1.

The resilience of a community with respect to potential hazard events is determined by the degree to which the community includes the public, private and the civil sector, has the necessary resources and is capable of absorbing disturbance and re-organizing into a fully functioning system (Cutter et al. 2008). This refers to the coping and adaptive capacity in the short- as well as in the long-term. The qualitative assessment performed by this survey-based concept allows identification of the main characteristics of the study area, expressed in stakeholders' risk perception, their intention to prepare, individual and societal behavioural patterns, as well as opinions of authorities' decision-making in the context of emergency and risk management. It also addresses potential improvements in emergency and risk management by means of multi-sector partnerships and additional adaptation measures for the area. Differences and inconsistencies in the survey answers given by society and the administration point towards the challenges that need to be dealt with in order to foster adequate community preparedness and adaptation to storm surge risk.

Different phases and elements are used to describe the coping and adaptive capacity of a community through time. These include institutional, social and legal dimensions. The various preparedness[14], response and recovery steps to be taken by institutions and society, as well as the required policy instruments, are shown in Figure 3 (blue boxes). Orange boxes represent the factors which influence action by institutions and society.

The performance in the preparedness phase will determine the success in the subsequent emergency and recovery phases. It follows that the preparedness phase must be based on sound risk analysis and supported by formal institutional, legal and budgetary capacities. Accordingly, institutional, social and legal dimensions should all be considered since failure or deficits in one dimension could turn the entire risk management and/or emergency process partially ineffective or, at worst, invalid.

[14] In this framework preparedness is defined as the knowledge and capacities developed by governments, professional response and recovery organizations, communities and individuals to effectively anticipate, respond to, and recover from the impacts of likely, imminent or current hazard events or conditions following the definition of the UN/ISDR (2009).

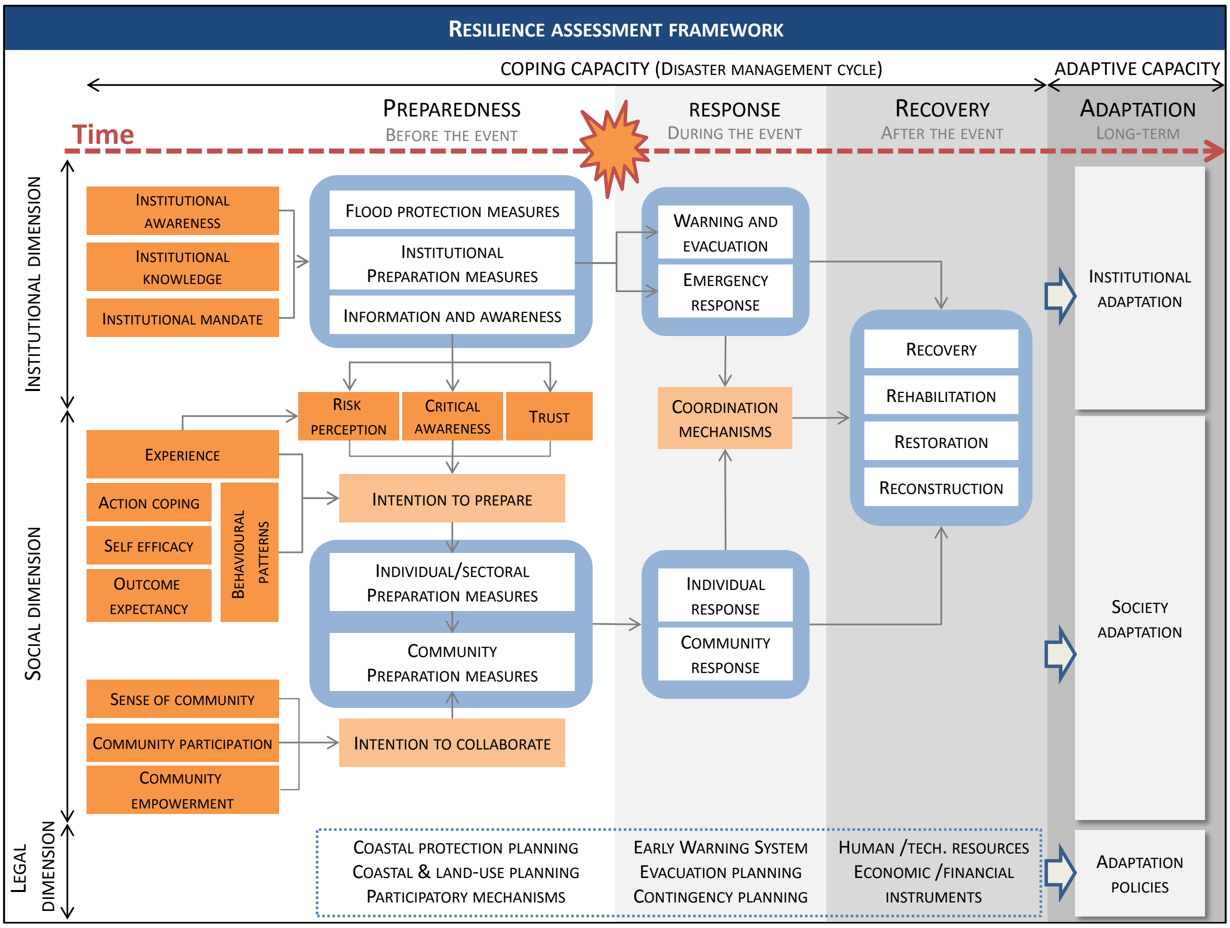

Figure 3 Resilience concept as a basis for designing the questionnaire, applied to understand the coping and adaptive capacities through time and institutional, social and legal dimensions (González-Riancho et al. 2015)

The institutional dimension in adapting to storm surge risks includes improvements in every task that forms part of the disaster management cycle (González-Riancho et al. 2015; UN/IOTWS 2007; González-Riancho et al. 2014). This includes flood protection measures, vertical and horizontal coordination, public information and awareness, early warning systems, evacuation planning, emergency protocols, contingency planning, etc., as well as a range of recovery options. Institutional awareness and knowledge of storm surge risks, as well as the existing mandatory provisions for managing storm surge risks, will affect the implementation of each step. In contrast to institutional adaptation, social adaptation is voluntary and more difficult to understand due to the variety of societal values, risk cultures, perceptions and dynamics. The voluntary nature of society’s behaviour means that society’s potential adaptation to storm surge risks can only be traced through “intentions”, which are understood as the cognitive representation of a person's readiness to perform a given behaviour, and considered to be the immediate antecedent of behaviour (Ajzen 1991).

Meeting social and institutional requirements is essential if society’s resilience to catastrophic storm surge events is to be enhanced. This demands close collaboration. Coupled institutional-social assessment in Case Study 3, similarly applied by Becker et al. (2011), is complemented by assessment of the legal dimension, in order to incorporate those policy requirements and instruments which condition adaptation (González-Riancho et al. 2015).

In Case Study 3 the stakeholder survey focuses on the assessment of community resilience according to the EHIUC concept. The structure of the survey reflects the disaster management. The online survey targeted stakeholders dealing with storm surge management along the Wadden Sea coast. It included a wide variety of stakeholders, e.g. representatives of the main socio-economic sectors (agriculture, tourism, industry, culture and environment), relevant administrative actors (e.g. coastal protection, emergency management, local administration), relevant non-administrative actors (such as NGOs, the business sector) and administrative levels including national, state (*Länder*), county (*Amt*), district (*Kreis*), and community (*Gemeinde*). Implementation of the survey takes place for each district along the coastline.

A first survey took place in the district of Dithmarschen in spring 2014. A second survey took place in the district of Nordfriesland in fall 2014, which completed the results for the Land Schleswig-Holstein. The survey is still in progress for the districts of Lower Saxony to complete the results for the entire German Wadden Sea coast.

To summarize, the concept described shows the linkages between the institutional, social and legal dimensions within risk management, with the aim of enhancing community preparedness, emergency management and long-term adaptation (González-Riancho et al. 2015). Moreover, in the context of Case Study 3, the concept presents insights into the concerns and interests of different sectors, as well as the current perception and awareness of risks (and risk management strategies and measures) in wider society and different sectors. An extract of the most important results for the two districts of Schleswig-Holstein is presented in Chapter 3.2.

2.3 Assessing interlinkages between causes and consequences: Bow-Tie analysis of multi-risks

Findings from the participatory workshops with the WSF made clear that comprehensive risk management in the WSR recognizes the area as a multi-risk area in which risks are interlinked and dependent on each other. Risk assessment must preserve this multi-risk perspective. Against this background, causes and consequences of perceived risks need to be assessed on a broader scale for the WSR. Comprehensive knowledge of the causes of a specific threat, knowledge of the societal consequences that could result from a threat, and the interlinkages between different risks provide the basis for a comprehensive evaluation of necessary measures and actions.

Bow-tie analysis is a risk assessment method that is used to analyse cause and effect pathways of risk. It is used to show the linkages between causes and undesirable events and the resulting consequences. It provides a solid basis for identifying gaps and areas in need of improvement, as well as a feedback to actual management.

Case Study 3 uses a bow-tie analysis to assess causes and consequences of risks based on the results of the participatory workshops with WSF members. This approach facilitates a structured assessment of the WSR as a multi-risk area. Bow-tie analysis comprises all the typical analytical steps involved in risk assessment: *Identification of risks* was performed in a participatory process with the stakeholders in the first workshop, and an *estimation of the events or risks* was done via prioritization of risks. At that stage, the explicit definition of causes and consequences in the bow-tie diagram supported the discussion. The bow-tie diagram helped in improving awareness of potentially unacceptable impacts, and deciding where management (measures) should have high priority. With regard to the third stage of comprehensive risk assessment (*estimating the damage and impacts of an event*), bow-tie analysis offers the possibility to include quantitative damage assessment. This, however, was not done in Case Study 3, since the main focus of ENHANCE is on the processes that take place between single actors and stakeholders and the performance of an MSP.

The bow-tie diagram visualizes the complexity of risks in one image, which is easier to understand than a long description. The central point is the hazard (e.g. a storm surge) which has the potential to cause damage to society or the environment. A related central part is a resulting top event (e.g. dyke breach), which means loss of control over the hazard. Causes of the top event (sometimes described as threat) are described in the boxes on the left side of the diagram (see Figure 4). These causes could be multiple causes, as became clear from the participatory stakeholder process.

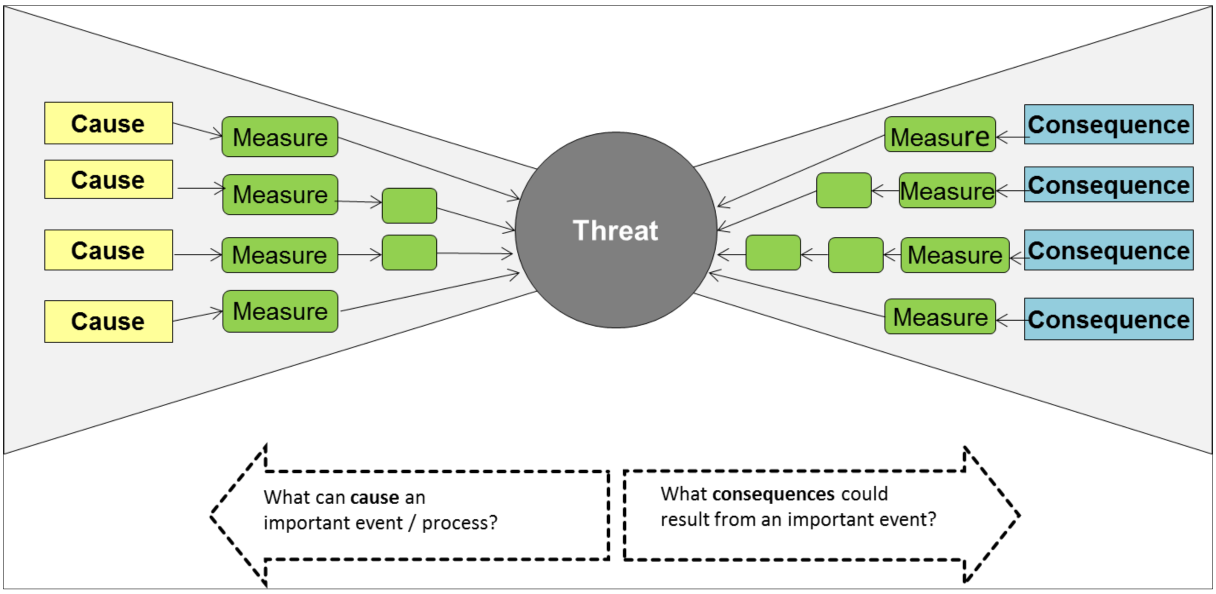

Figure 4 Schematic overview about the essential elements of the bow-tie diagram

The right side of the diagram depicts the consequences of the top event (threat). Of course, these can also be multiple consequences. Defining hazards and differentiating between its causes and consequences gives a clearer understanding of the risk and unwanted incidents and impacts. At this stage, measures can be elaborated for dealing with causes and consequences. This includes measures designed to avoid the loss of control, and measures designed to minimize the consequences of a loss of control. If elements of preventive and mitigating management and control are implemented and work successfully, the management process will be effective. Success means that the ability increases to manage the causes that lead to an undesired event, and that consequences of undesired events can be mitigated.

We chose the bow-tie approach due to its ability to visualize the complexity of risk assessment in an easily accessible format. For the participatory processes, having one picture of a complex system turned out to be highly beneficial. Regarding the broad range of natural, social and economic risks in the WSR, different scientific estimates of impacts and damages are available with different levels of detail and different overall scope.

The application of bow-tie analysis in risk management of natural hazards is rather new, especially in Europe. In the WSR the approach is introduced in order to enhance risk management processes. The origin of this method dates back to cause and consequence diagrams developed in the 1970s. Since the early 1990s the oil company Shell has made significant contributions to enhancing the use of the method. From 1990 onwards bow-tie diagrams have been actively used in safety reports for the petrochemical industry in the UK and later in the US (Salvi & Debray 2006). In the last decade the approach has spread outside of the oil and gas industry to include aviation, mining, maritime, chemical and health care to name a few. In most cases where bow-tie analyses were implemented, it has been highlighted that a multidisciplinary team is required to properly implement it (Rausand 2011).

Based on the characteristics described above, it became clear that this method is helpful in identifying the major objectives of current and potential future risk management processes in the WSR. Bow-tie analysis supported better understanding of the links between different issues and concerns raised by the stakeholders. In addition, it also facilitated identification of important starting points for enhancing risk management and applying it where it is most needed (which includes actions as well as processes). For detailed results of the Case Study 3 bow-tie analysis see Chapter 3.3.

3 Results of the risk assessment

Following on from the description of the analytical steps involved in risk assessment, Chapter 3 presents the results obtained. A comprehensive assessment is provided which includes the causes and consequences of storm surge risks and the interlinkages between these, as well as linkages with other risks in the Wadden Sea Region (WSR). The assessment of causes of storm surge risks focuses on the natural system, i.e. climate conditions and the topography of the area. Future changes in climate conditions can change the current situation and increase the risks of storm surges, so the available knowledge on the future development of climate change must be included. We analyse existing scenarios on changes in climate parameters in the WSR which have been developed based on dynamic and statistical modelling (see Chapter 2.1). In order to assess topography and anthropogenic alterations, we use flood maps to show the spatial dimension of increased storm surge water levels under conditions of climate change (see Chapter 2.1).

Dealing with the causes of storm surge risks means applying adaptive measures. Whilst climate change as such cannot be influenced by the coastal population, the topography can and has already been altered by coastal protection measures for the purpose of managing undesired events. The main challenges in storm surge risk management therefore result from the consequences of storm surge events. Such challenges already exist under current climate conditions and will probably increase due to climate change. Consequences occur in different sectors and at different levels and affect the economy, society and the environment. Different measures are already in place for mitigating these consequences, but all sectors agree on the need for improved and additional measures. Case Study 3 makes clear that enhanced (storm surge) risk management in the WSR has to focus on the consequences of storm surges in order to improve society's capacity for mitigating and successfully decreasing the risks resulting from hazard events.

Our assessment of the consequences employs quantitative and qualitative analysis:

- A quantitative assessment of storm surge consequences and the potential damage caused was carried out in an analysis of the existing state-of-the-art damage modelling approaches for the Wadden Sea coast (Chapter 3.1).
- A qualitative assessment of storm surge consequences and current storm surge management was undertaken in order to include cultural frames, perceptions and behaviour. The focus lies on different concerns and rationalities of the stakeholders involved (Chapter 3.2).
- In a third step, a qualitative risk assessment was performed in order to analyse the interlinkages of causes and consequences. For this step a bow-tie analysis was carried out. Apart from the interlinkages between causes and consequences, this approach also addresses interlinkages between the multitude of risks identified for the WSR; a fact that was given great importance in the stakeholder discussions (Chapter 3.3).

3.1 Assessing consequences of storm surge events: Literature review on storm surge damage modelling

In the last decade, considerable improvement has been achieved with regard to damage- and risk analyses. Results from damage modelling can offer support for decision-making processes, especially if modelling includes the assessment of the cost-benefit ratio and is able to monetarily compare different measures. For Case Study 3 it is important to question the information and insights that can be obtained from damage modelling – keeping in mind that storm surge damage assessment is a highly political issue in the WSR. What kind of information is already available, and does information exist at the trilateral scale for the whole WSR, as this scale is of major interest of the Multi-Sector-Partnership (MSP)?

In 2009 Schwerzmann & Mehlhorn published the results of their study on "the effects of climate change: an increase in coastal flood damage in Northern Europe". In this study, the global climate emission scenario A2 was used in order to determine the potential climate changes in the North Sea area. A hydro-dynamic model was used to transform this information into storm surge events taking into account the local tidal situation. Based on these data three different sea level rise scenarios were developed.[15] Taking into account current storm surge protection measures and water depths resulting from sea level rise, the Swiss Re loss model transformed these water level depths into financial losses. The expected annual losses under current conditions in the North Sea Region (including United Kingdom, Belgium, Netherlands, Germany and Denmark) is about EUR 0.6 billion. These losses could increase under expected climatic changes up to an annual loss of EUR 2.6 billion. This means that losses can increase fourfold compared to today's level (Schwerzmann & Mehlhorn 2009).

The chosen climate scenario does not reflect the upper boundary of climate projections (neither IPCC 2007 nor the SRES scenarios of IPCC 2014). An insight into expected annual losses for each country is only given in the percentage of increased losses that can be expected under future climate conditions (defined by the two scenarios including sea level rise). For all countries an increase in annual losses is expected between 100% and 900% compared to today (Schwerzmann & Mehlhorn 2009). For the three Wadden Sea countries the biggest annual loss is projected for Denmark, with fewer losses expected for Germany and the Netherlands. Nevertheless, even assuming to the IPCC scenario of 37 cm sea level rise annual losses will increase by approximately 900 % in Denmark, 400 % in Germany and 150 % in the Netherlands.

This study is an example of how storm surge damages can be assessed – and it underlines the challenges involved in expressing loss at a large scale. The HZG (former GKSS) collaborated with Swiss Re and the University of Bern by providing storm surge data for this study. Based on the experiences of this study, the sensitive nature of attributing monetary values to different land uses, infrastructure and economic factors has become apparent. Since carrying out the study, HZG colleagues have warned of projections that are too

[15] Scenario 1: 0 cm sea level rise , to model wind-only effects, Scenario 2: 37 cm sea level rise based on scenario A2; Scenario 3: 50 cm sea level rise as hypothetical scenario (Schwerzmann & Mehlhorn 2009)

general and could be misinterpreted as alarming. But what is the situation with respect to damage modelling on smaller scales – the national, regional and local scale?

On a national scale, especially along the German Wadden Sea coast, analysis of existing research shows that most of the projects are linked and often build on each other. The most important and central project outcomes form the basis for subsequent assessment. The following compares and assesses the methods applied, the data and the type of damage estimation. For a comprehensive summary of the assessment see Annex A.

The analysis is based on the following recent research projects:

- FLORIS – Flood Risks and Safety in the Netherlands (2001 to 2005) lead by the Dutch Ministry of Transport and Waterways with the purpose of gaining an understanding of the consequences and the probability of flooding in the Netherlands;
- MERK – Microscale evaluations of risks in flood prone areas (2000-2002, Research and Technology Centre, West Coast, University of Kiel);
- ComRisk – Common Strategies to Reduce the Risk of Storm Floods in Coastal Lowlands (2002 to 2005) which was a common project of North Sea Region coastal defence authorities and aims at improved risk management for coastal flood prone areas;
- SAFECOAST – Sustainable Coastal Risk Management in 2050 (2005-2008) lead by the Dutch Ministry of Transport and Waterways; with the general aim to develop a sustainable and balanced development of the low-lying flood prone areas against the background of climate change;
- Xtrem RisK – Extreme storm surges at open coasts and estuarine areas: Risk assessment and mitigation under climate change aspects (2008-2012) lead by the Leichtweiß-Institut University of Braunschweig. The project aimed to improve the understanding of uncertainties in storm surge predictions, the influences of morphological changes, and the joint effect of extreme water level and sea waves and to quantify the overall flood risk for an open coast and estuarine areas;
- HoRisK – Flood risk management for coastal areas (2009-2013) lead by the RWTH Aachen University which aimed to derive approaches and methods for coastal protection to develop application-oriented damage and risk analysis as a basis for hazard mapping, flood risk mapping and flood risk management plans.

All these projects were dedicated to the **small- and micro-scale level**. For example, in the COMRISK project, single cross-border coastal flood unit were analysed with a length along the coastline of 25 km and a landward width of 15 km (Verwaest &Trouw 2005). One example is the island of Langeoog (approximately 20 km² in total). Micro-scale analyses were performed in the MERK project, e.g. in St. Peter-Ording, Kaiser-Wilhelm-Koog on the German North Sea coast. The results up to the 5 m contour line allow a comparison with the damage potential of the area analyzed within the MERK-project[16]. Xtrem RisK carried out their analysis on the island Hamburg-Wilhelmsburg, an urban district of the city of

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[16] MERK (micro-scale analysis) for the island of Langeoog: Total value of damages according to the applied approach due to different elevation level: Total value up to 19.5m above sea level: 1.115.893.800 €; total values up to 5.5m above sea level: 931.522.000€; total values up to 5.0m above sea level: 864.209.900€.

Hamburg[17], and for the small towns of Hörnum and Westerland on the island of Sylt – both were exemplary for estuarine areas and open coast (Oumeraci et al. 2012). Some projects took place at a meso-scale, like SAFECOAST where flood units[18] related to single dike areas were taken into account. This project emphasizes the need for local information in practical application. In storm surge management locality has a decisive influence on damage and risk analyses.

With regard to the methods applied in the different projects, different levels of detail were reached. Apart from the methodological challenges of deciding on a hazard scenario, it is a major **challenge to determine the coastal protection measures** applied in the region and **assume realistic failure mechanisms** and/or overflow scenarios. In COMRISK the model for sea dikes developed by Kortenhaus (2003) was used for deterministic and probabilistic calculations in the hazard analysis. It comprises 25 failure mechanisms with a total number of 87 input parameters (Piontkowitz et al. 2005).

In all research projects analysed, damages are estimated in different damage categories, each of which is related to certain estimations of values. The projects differentiate between direct, indirect and tangible and intangible damages. Key aspects are the level of detail and the range of damages considered in the assessment of values, as these are essential for the level of detail of the estimated final risk. In COMRISK only direct economic damage and human casualties are considered as consequences of a flood event.[19] Thus, significant consequences are not taken into account, e.g., damage to nature, psychological damage, and damage to the economy outside the flooded area. FLORIS includes three different categories. "Direct damage-material" refers to the damage caused to objects, capital goods and movable goods as a result of direct contact with water. "Direct damage - due to business interruption" is defined as damage due to business interruption, i.e. the commercial losses caused by lost production. "Indirect damage" comprises damage to business suppliers and customers outside the flooded area and travel time losses due to inoperability of roads and railways in the flooded area (Ministerie van Verkeer en Waterstaat 2005).

All projects emphasise the huge amount of data needed for each approach. The project reports confirm that in order to meet the aims of the project, and moreover, to meet the demands of users, specific **levels of detail with regard to spatial resolution** as well as selected **levels of diversity in categories of damages** have to be ensured. SAFECOAST

[17] The results of the Xtrem RsiK project for the intersection of flooded areas and risk elements for Hamburg Wilhelmsburg (small-scale analysis) results in an estimation of damages at a range of 0 € to 325.000 € related to different scenarios. Direct damages vary within the three selected scenarios (in Mio €) between a total amount of damages of 3,44 up to 5.495,32 million €. Indirect damages (in Mio €) related to 3 different scenarios vary from 0,22 million € up to 87,5 million € (Oumeraci et al. 2012).

[18] With regard to the requirements in coastal protection strategies the study area was divided into so called flood units. Each flood unit represents the area that becomes flooded when a single dike is breached during a storm surge. Normally, the flood units do not fit with the municipalities. However, for coastal defence planning purposes it is important to know what potential damages exist in each flood unit. Hence, the values per municipality were broken down to these lower units (Ministerie van Verkeer en Waterstaat 2005, p.6)

[19] Flood event here and in the following section is defined as the intrusion of surface water in an embanked or low-lying area caused by storm surges. The cause for this intrusion is specifically defined in each project / in each scenario; mostly as a consequence of a dyke breach or as a consequences of overflow of coastal protection measures

pointed out that a high level of spatial resolution demands extensive scientific input and takes a lot of time. The authors stated that almost 90% of total project time was used to compile and process raw data into a homogeneous database (SAFECOAST 2008).

In many cases, the spatial distribution of values in the damage categories is assessed based on land use and the ecological characteristics of the research area. GIS approaches were applied in order to determine the damage (per cell) on the basis of land-use maps e.g. digital land use model from the ATKIS – Topographic-cartographic-information system for Schleswig-Holstein, Germany – as performed in SAFECOAST and HoRisk.

The final **calculation of damage** is based on a damage function calculated from the estimated and expected damage per unit. **Damage functions** represent the development of damage as a function of the depth of inundation, and the necessary replacement of values or maximum damage values for defined categories. Different approaches were applied in the different projects.

FLORIS approaches the calculation of damage based on a damage function that includes a specified damage factor. The damage factor is a figure between 0 and 1, considering the inundation depth and the current velocity based on the topographical and hydrological situation in the area. The damage factor is one possible option to integrate the spatial and hydrological conditions into the damage function. Each damage function consists of a maximum damage sum and a damage factor. The maximum damage sum is the maximum damage which can occur in a flooding scenario.[20] It is based on the replacement value and includes a damage function for each land use form in a mathematical unit (Ministerie van Verkeer en Waterstaat 2005).

COMRISK used a method developed by Flanders Hydraulics Research for Vlaanderen in combination with the method of Rijkswaterstaat (Directorate General of public works and Water management, the Netherlands) for the Netherlands. Direct economic damage and human casualties are considered as the consequences of a flooding event. The methods are based on a GIS approach. The maximum damage per cell is determined on the basis of land-use maps and supplementary information. The damage in the area is calculated for each category of damage based on damage functions for all potential damage categories. Combining the two sets of data produces the damage per cell. A similar method is used for casualties, with the difference that the maximum rise velocity (Vlaanderen) or the maximum horizontal velocity (the Netherlands) is also used as an input parameter (Verwaest & Trouw 2005).
The damage functions applied in HoRisk are basically dependent on inundation depth. In some parts they are also dependent on the retention time of flood water and flow velocity in the area. The damage calculation in HoRisk took into account the maximum flooded areas as

[20] Based on the chosen approach the average economic damage for different flood scenario includes: Noordoostpolder 1,900 million €; Zuid-Holland 5,800 million €; Land van Heusden /De Maaskant 3,700 million € (Ministerie van Verkeer en Waterstaat 2005, p. 58).

an important element (Meyer 2005). Calculation is performed by a 1d/2d numerical simulation[21].

A slightly different approach was applied by SAFECOAST. Assuming that economic values and inhabitants are primarily located in residential areas, the proportion (%) of residential sites per municipality within each flood unit was calculated. Similarly, the proportion (%) of agricultural area or rather agricultural values per municipality was determined for each flood unit. From these estimated percentages the total value per flood unit is calculated. With a digital terrain model (DTM) values can be calculated for different inundation intervals in each flood unit (Ministerie van Verkeer en Waterstaat 2005).

Analysis and comparison of the existing projects show that each project is using its own damage functions. Irrespective of their type, all require a large amount of detailed spatial information, e.g. inundation depth, storage capacity of the area, hydraulic information on flow velocity, etc. A precise answer to questions of potential damage and loss of values depends on the accuracy of the acquired data.

The comparative analysis confirmed that a multitude of research results are available for the WSR. Discussions with experts from science and the coastal protection authorities made clear that determining the consequences of flooding events is a highly sensitive, political issue, especially with regard to monetary values. Little research has been carried out at the national or transnational level, and damage estimates are of very limited significance and validity. The majority of research focuses on the meso- and micro-scale level. The most important challenge is an adequate process of damage estimation. This includes the definition of damages and the level of detail to be included, defining the categories of damages, data availability with regard to level of detail, which is often very high, and last not least assigning values to the different categories, taking into account different estimations and priorities. The definition of failure modes (of the dyke system) poses another difficult task to scientists and/or coastal engineers. In the projects several different failure modes (including a multitude of parameters) were included. The comparison also revealed that user demands, including the demands of decision-makers, can only be met by site-specific application, including the level of detail to be included, the spatial resolution required and adequate diversity in the damage categories chosen.

Administrative coastal engineering staff has learned the hard way that published figures are a political issue and can cause disturbance in the affected population. Science has a social responsibility and must be careful not to treat damage calculations as an academic playground.

[21] Damage estimation for the island of Wangerooge (micro-scale): The general part of the damage potential exists at a range of 101 €/m2 up to 300 €/m2. However, there are areas that potential values reach an extend of up to 900 €/m2 (Lambrecht et al. 2014)

3.2 Assessing stakeholder rationalities and concerns in storm surge management: Results of the survey in Dithmarschen and Nordfriesland

In addition to the quantitative assessment presented in the previous Chapter, a qualitative assessment of storm surge consequences and current storm surge management is presented on the basis of a personalized online survey. Case Study 3 considers risk to be deeply connected to societal frames, and as such influenced and shaped by perceptions, interests and priorities of different actors, sectors and interest groups. These characteristics guide the processes and actions of integrative risk management. The results of the survey on storm surge risk management in the northern part of the German Wadden Sea coast will offer insight into different rationalities held by stakeholders from different sectors (for a more detailed description see Chapter 2.2.2 and González-Riancho et al. 2015). The results of the survey provide detailed information on stakeholders' concerns with regard to the consequences of heavy storm surge events. It also includes analysis of the perceived efficiency of current storm surge management and stakeholder demands for improvement in decision-making processes. The survey contributes to risk assessment by identifying who is and should be responsible and how stakeholder involvement should be organized.

The questionnaire consists of 20 closed questions in three categories. The following subsection presents a selection of the results. A pilot study of this survey was performed in the district of Dithmarschen (results are published in González-Riancho et al. 2015), followed by the survey in Nordfriesland. The other parts of the Wadden Sea will be covered in ongoing work.

An inventory of stakeholders in the respective survey area was compiled with the support of experts on storm surge hazard and emergency management and/or the socio-economy of the study area. Survey participants include experts involved in management processes and experts whose activities could potentially be affected by storm surge impacts. For Dithmarschen 43 stakeholders were identified due to their representativeness and relevance in the region and contacted by phone and email. After several rounds of invitation and reminder, 16 answered the questionnaire. For Nordfriesland 120 invitations were extended by phone and/or email, out of which 40 answered to the questionnaire. For both districts the statistical sample appears to be small; however, it can be considered comprehensive for the study area, since at least all types of private stakeholders, the administrative levels and sectors are represented.

The first category of questions dealt with the knowledge of stakeholders of storm surge hazards. This included the potential impacts and consequences of storm surges, what to do in case of an event, the responsible authorities, flood protection measures and preparedness/recovery options.

Analysis of **stakeholders' perceptions and concerns with respect to major consequences** (an equivalent term for consequences in the survey was "impacts") highlights that stakeholders in both districts expect major damage to infrastructure, the economy and social disruption. Human losses and environmental impacts are of secondary concern to the stakeholders (see results by district Figure 1).

The degree to which knowledge and awareness could be transformed into preparedness behaviour was estimated by asking about the availability of storm surge risk information. Big differences became apparent between the two districts: in Nordfriesland the majority of the participating stakeholders feel well informed in most of the categories, whereas in Dithmarschen, the general level of information is low. Almost half of the respondents did not know whether information on any of these issues was available. Similarities can be detected with regard to the availability of information on potential social and economic impacts. Given that stakeholders are mostly concerned about storm surge impacts on the economy, infrastructure and social sphere, a need for action in these spheres becomes obvious. The current situation, in which quantitative, especially monetary assessments of storm surge damages represent a highly sensitive, political issue, represents a clear call for different action in order to meet the concerns of stakeholders and society with respect to successful risk management strategies and actions.

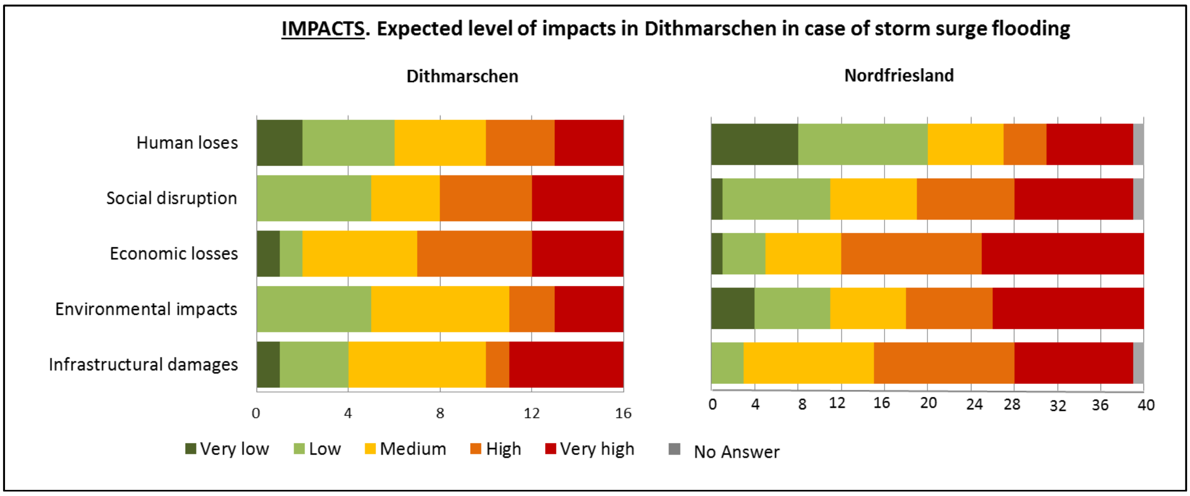

Figure 5 Expected level of impact of storm surge flooding answered by Dithmarschen stakeholders (left, sample 16) and stakeholders from Nordfriesland (right, sample 40)

Need for action can also be identified on the basis of answers to a knowledge-based decision-making question. This question aimed to evaluate to what degree stakeholders consider risk information to be included in sectoral planning in the study area (see FFigure 6). Both districts deliver similar answers. There is consensus on the in-depth consideration of storm surge risks in coastal protection schemes. This rather obvious statement, however, can be interpreted as strong agreement with, and trust in coastal protection schemes and their highly protective qualities.

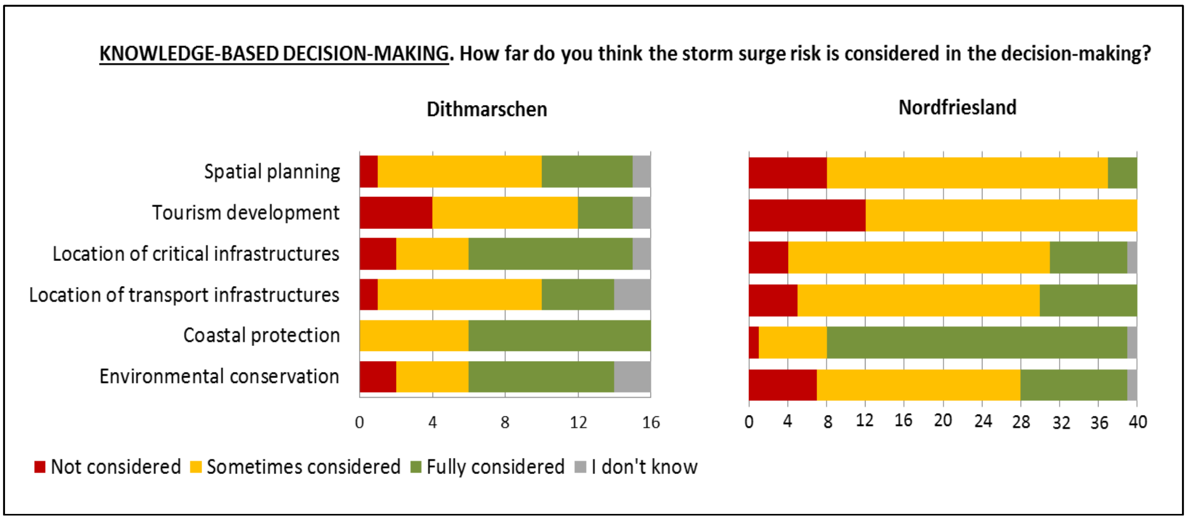

Figure 6 Extend of knowledge of storm surge risks considered in decision-making processes; Left: answers from Dithmarschen, sample 16, right: answers from Nordfriesland, sample 40

Less consideration is given to storm surge risks in spatial planning, tourism development and transport infrastructure planning. These results suggest a lack of risk knowledge-based sectoral planning. This lack, in consideration of the expected major impacts of storm surge damages, calls for an improved, integrative and broader perspective in storm surge risk management. Storm surge risks should be included more broadly in decision-making processes to minimize the damages and consequences expected by society.

Practical measures to adapt and reduce consequences of storm surges were also assessed. **Where measures should be put into practice? And who should be responsible?** Asked to rate the effectiveness of current flood protection measures, most of the stakeholders agreed on the high effectiveness of hard protection measures, i.e. dyke systems and flood gates. Soft protection and spatial planning measures, i.e. coastal nourishment, building codes and coastal setbacks, received lower effectiveness ratings (see Figure 7). This result shows the prevailing high credibility of hard engineering measures in the study area und underlines the high trust in hard protection measures in storm surge management.

Participating stakeholders were asked to identify responsible authorities in storm surge management. Results disclosed that the current structure in storm surge management, including multiple actors on different levels (federal, district and local level), is well known and acknowledged by the participating stakeholders. Multiple actors are currently active in storm surge management and the stakeholders appreciate this multitude. An interesting fact is that especially in Nordfriesland key persons have different responsibilities and multiple offices – with all its advantages and potential disadvantages.

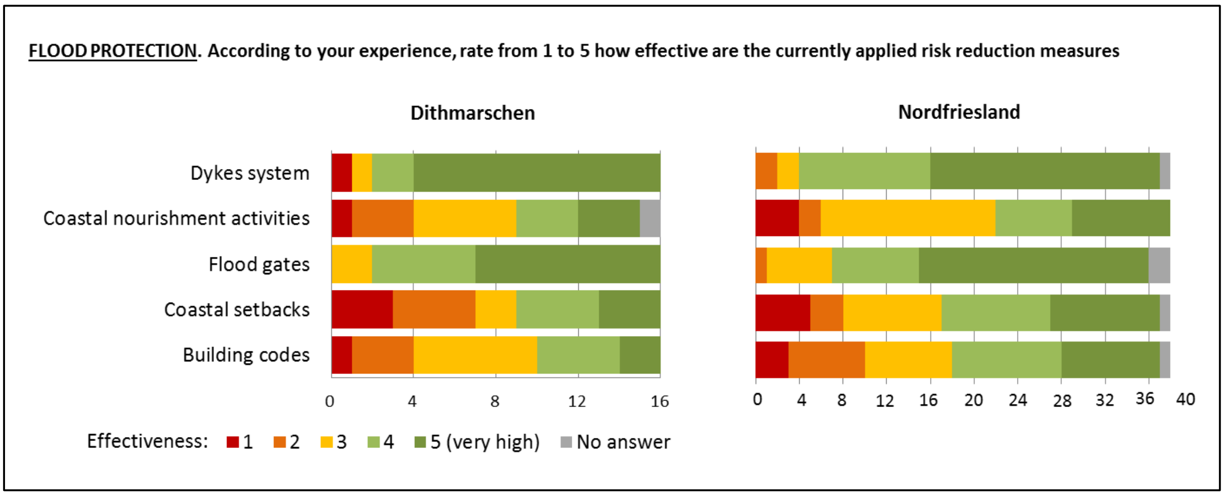

Figure 7 Perceived and experienced efficiency of applied risk reduction measures; Left: Answers Dithmarschen, sample 16, right: Answers Nordfriesland¸sample 40

The second category of questions dealt with sector and community preparedness for storm surge risks. This included factors conditioning behavioural patterns, protective behaviours as well as community interaction. Stakeholders were asked about the level of involvement their sector should have in risk management. The self-assessment of their **current and desired active involvement in storm surge risk management** provides essential information on the level of activity and the necessary commitment of different stakeholders and sectors in the storm surge risk management process. In both districts, Dithmarschen and Nordfriesland, the majority of stakeholders support active involvement rather than just being informed. In Dithmarschen the majority of stakeholders see a need to be involved in risk management as they can and want to contribute to successful storm surge risk management. In the district of Nordfriesland the majority stated that their sectors are already successfully involved in risk management processes. These results go to some extent align with current sectoral involvement in storm surge risk management. This is underlined by the answers to the question on behavioural patterns, where stakeholders were asked to pick the statement that fitted best with their sector's action. For both districts, approximately half of the respondents agreed that the interests and actions of their sector were already included in the development of risk management strategies by the authorities. Almost one quarter of the respondents in each district stated either that a) the sector could take action to reduce the risks but is not working on it yet or b) the potential impacts (of storm surges) on the sector can only be reduced by risk management authorities (Figure 8). The behavioural pattern demonstrated the respondents' current proactive behaviour and preference for participatory risk management options. Despite existing participatory schemes there is still room for improvement.

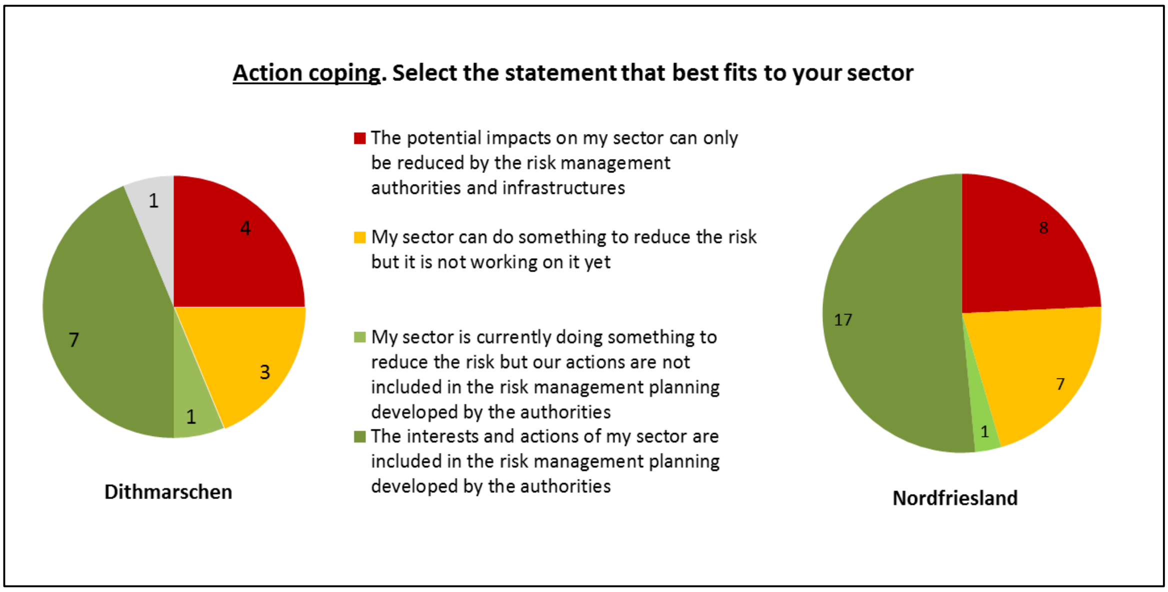

Figure 8 Behavioural patterns of sectors; Stakeholder of Dithmarschen (left) and Nordfriesland (right) selected to statements that fits best to their sector; figures in total per category in each district

The third category of questions addressed the potential coordinating mechanisms along with policy and economic options to foster the adaptation to the storm surge hazards. Special focus was given to a possible MSP, enquiring about potential participants as well as gains and challenges for multi-sector involvement in managing storm surge risks. The results on potential MSP are still being analysed and will be presented and discussed in detail in the next deliverable.

To summarize the results of the personalized online survey, there is varied understanding of the processes involved in storm surge protection, and broad agreement on the potentially beneficial involvement of stakeholders. Based on the answers provided, the Wadden Sea community in Schleswig-Holstein seems prepared to deal with the causes of storm surge events. This is highlighted by the deep trust in adaptive measures such as hard engineering measures. In contrast, the Wadden Sea community in Schleswig-Holstein seems less prepared to deal with the consequences of storm surges. Economic losses and damage to infrastructure seem to be perceived as the most drastic consequences of heavy storm surge events and threats to the Wadden Sea communities.

Overall, stakeholders therefore feel secure, but nevertheless identify points of action to enable their greater involvement in storm surge risk management. The large degree of trust expressed in traditional engineering measures highlights how deeply this traditional handling of storm surge crisis situations is rooted in societal behaviour. According to the participating stakeholders, knowledge on storm surge risks is successfully integrated in coastal protection but less so in related fields, e.g. spatial planning or tourism development. Stakeholders consider that improvements in these decision-making processes could enhance the achievements of storm surge risk management.

The question of what risks we are prepared to take, and how this should be managed, is answered by the ongoing trust in hard engineering measures and the respondents' current proactive behaviour. Moreover, respondents show increased interest in participatory risk management options. Knowledge of these stakeholder perspectives helps to open the door to collaborative, participatory processes, which could result in permanent MSP involving stakeholders from different sectors. Stakeholder concerns with respect to the consequences of storm surges, their view on gaps in current storm surge risk management, as well as their estimates of their own active involvement in storm surge risk management set the scene for further negotiation of improved strategies, measures or processes to rethink storm surge risk management along the Wadden Sea coast.

3.3 Assessing interlinkages: Multi-risk assessment in the Wadden Sea Region

The results presented above highlight the importance of causes and consequences of storm surge risks. However, comprehensive risk assessment also needs to analyse the interlinkages between different risks which might result in new demands for measures and actions. The Case Study 3 used a bow-tie analysis to carry out this analysis. As stated in Chapter 2.3, bow-tie analysis is a method which can facilitate greater understanding of the complexity and interrelationships of causes and consequences. Bow-tie analysis offers the possibility to analyse interlinkages between different risks; as such it meets the requirements of comprehensive risk assessment in the WSR (the first participatory workshop with the WSF emphasised the WSR as a multi-risk area). Storm surges are perceived as one major risk for the WSR – for which current management is perceived to work properly. But other threats were also considered to pose major risks to the Wadden Sea communities. According to the stakeholder workshop, these fields need more urgent risk management than storm surges (Gerkensmeier et al. 2014). Given that different risks of high priority occur in the WSR, and that these are interlinked and dependent on each other, risk assessment must also take a multi-risk perspective. The findings of the bow-tie analysis, resulting from the participatory processes in two WSF workshops, are presented in the following chapter, partly illustrated with bow-tie diagrams.

3.3.1 Multi-risks on multi-scales – outcomes of the first workshop using the bow-tie analysis

The bow-tie analysis helps to structure the discussion by distinguishing causes, consequences, measures and their interlinkages. In Case Study 3 the development of the bow-tie diagram evolved from the results of the first workshop which were collected in a combined individual and group response process.[22] This approach of practical implementation is slightly different to the usual scopes of application for bow ties.
The results were later assigned to the different categories (causes, consequences, measures, threat). In this way, the perceived risks and stakeholder concerns with respect to current management set the scene for the bow-tie analysis. Based on these inputs, the central elements of the diagram (the knot, representing the major issue that the stakeholders are

[22] The discussion was moderated by using the table-set method, combining individual and group response to a certain question or task. This methods help structuring an equitable group discussion and fosters the discussion of different positions.

concerned about) were extracted and identified as crucial for the WSF members. This is different from other risk management processes, where the central element is mostly predefined by a certain strategy or measure whose effectiveness is to be analysed, or a certain problem/research question that is to be analysed. All comments, inputs, and discussions of the first workshop could be assigned to one of the structural categories identified. Based on this attribution different clusters were developed. The final result highlights three major bow-tie clusters of issues and concerns mentioned by the stakeholders. For each of the clusters a bow-tie diagram was developed – with one central issue, its related causes, consequences and (if applicable) available prevention and mitigation measures. In addition, it is important to highlight the linkages and connections that exist between the three bow-ties. The clusters are not independent form each other. Feedback as well as cascading effects between the thematic clusters could influence the performance of the others. Therefore, linkages and connections have to be taken into account in risk management, both with regard to specific, local activities as well as on a more general perspective.

The three resulting bow-ties were clustered around the central issues of environmental or climate change, imbalanced development and demographic change. We will give an overview of the causes and consequences of each. A more detailed, visual presentation of all issues mentioned, including comments on measures, strategies etc. can be found in Annex B.

Cluster: Environmental change

The first cluster revolves around the threat of climate change resulting in environmental changes that affect the communities in the WSR. Stakeholders are concerned that changed environmental conditions due to climate change will hamper development in the WSR because of social, economic and natural limitations. The main causes of this threat are increased frequency of heavy storms and, partly resulting from increased storm activity, an increase in the frequency and amplitude of storms surges.

In addition, increased precipitation and rising sea levels are thought to have a negative impact on coastal communities. All of these causes result from climate change and develop in negatively changed environmental conditions. Ultimately, all of these events are thought to hamper development because of negative changes to natural conditions (see Figure 9). Numerous aspects were named that are specifically thought to hamper development in the WSR (see Figure 9). Just to name a few: different kinds of flooding events (due to storms surges as well as due to inland flooding), increased coastal erosion, rising ground water levels and impacts on agricultural activities in the area. The bow tie identified a direct link to demographic change in the WSR (see Figure 9).

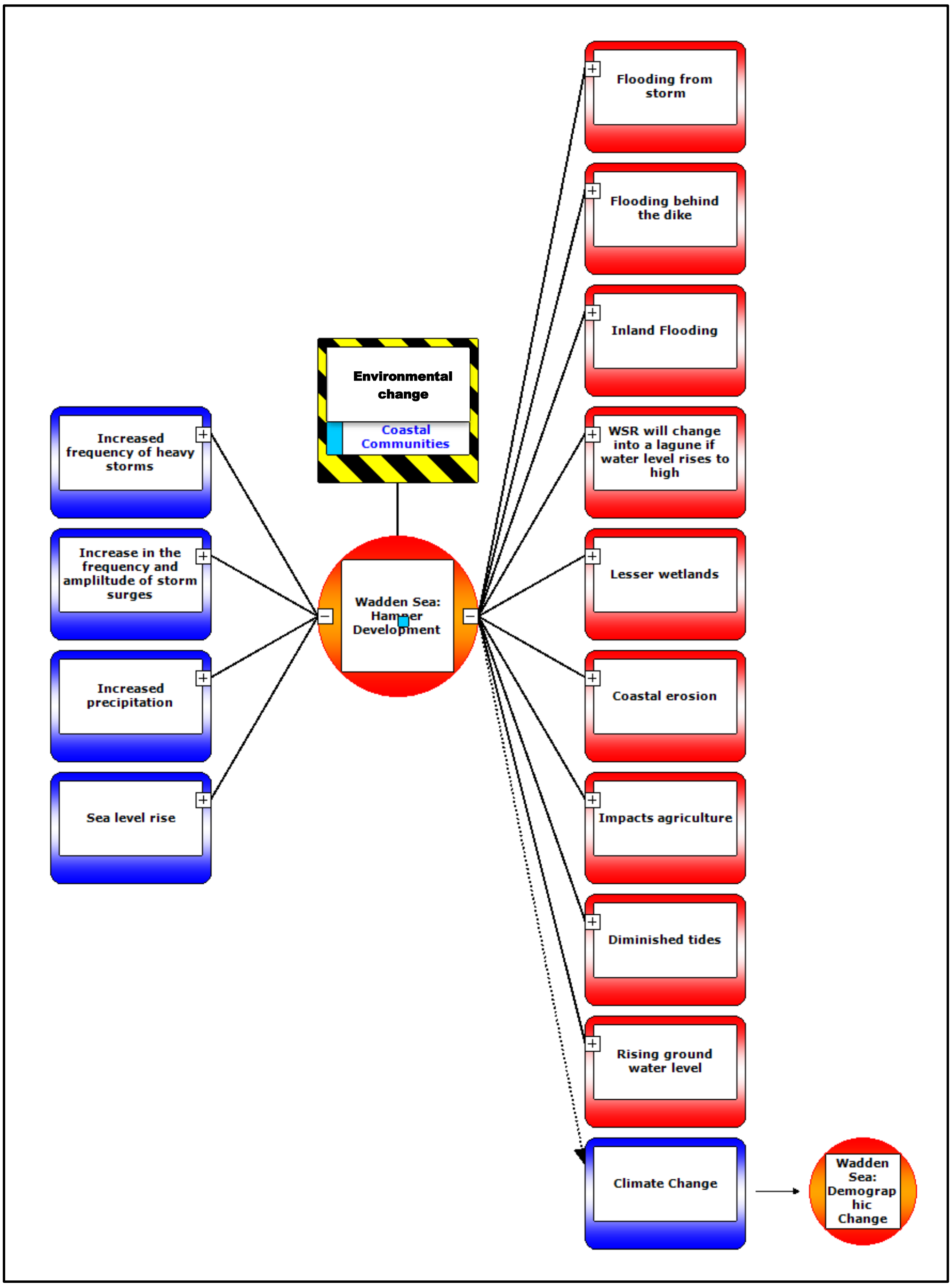

Figure 9 Bow-tie diagram concerning the threat of environmental changes due to climate change affecting the coastal communities in the WSR

Cluster: Imbalanced Development

The second bow-tie diagram concerns imbalanced development in the WSR. This mainly refers to the prospect of uncoordinated, unsustainable development in the WSR. There is a perceived imbalance between different lines of development (social or economic development of the region, as well as development in environmental sector); impacts on other sectors vary in intensity and sectors often fail to consider other sector's needs. Stakeholders expect the environment to be most affected by such imbalanced development. Figure *10* lists the causes and consequences of such imbalanced development in the WSR.

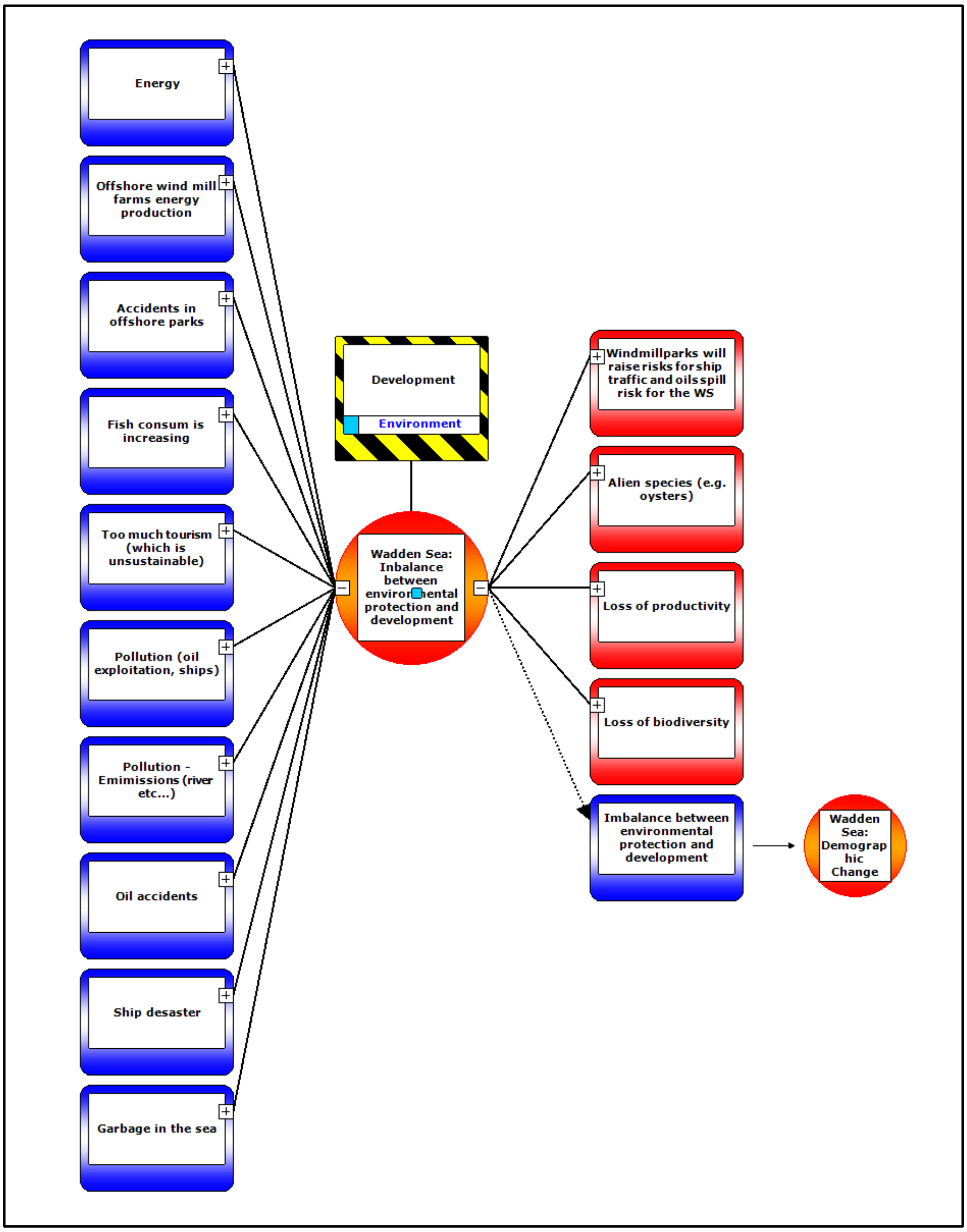

Figure 10 Bow-tie diagram evolving around the worries about an imbalanced development between social, economic and environmental interests

The emphasis of this bow-tie has shifted to the left, where the causes for the perceived imbalance are listed. Amongst others, these relate to issues of energy supply, e.g. offshore wind farms and possible accidents in these, causes linked to developments in the fishing sector, e.g. increased consumption of fish. Furthermore, with regard to the tourism sector excessive, unsustainable growth is also perceived as negative. Different sources of pollution, e.g. oil spills, accidents, emissions and marine pollution, also concern WSF members.

Major consequences of imbalanced development in the different sectors will, amongst others, lead to loss of productivity and biodiversity and an increase in alien species in the WSR. In general, the bow-tie makes clear that imbalanced development in the WSR will directly impact on and increase the challenges of demographic change in the WSR. Interlinkages and feedback exist to several of the consequences mentioned in the cluster of climate change.

Cluster: Demographic Change

The short description and visualization of the first two bow-tie diagrams make clear that both are linked to demographic change, which is addressed by the third bow-tie. Stakeholders are mostly concerned by the lack of balanced development, which they perceive as a major driving force of demographic change. The consequences of demographic changes will affect the coastal communities in all three countries in a similar, mostly negative way (see Figure 11). With regard to causes, stakeholders mentioned an increased NIMBY mentality (Not In My Back Yard) and increased individualism („I am important") which influence social processes. Limited and egotistical thinking is a challenge for balanced development, and there is the feeling that society's concerns are increasingly ignored by politicians. Stakeholders also mentioned that risks as such are sometimes not perceived and consequently, governance is lacking. Consequences of these processes include unemployment, out-migration away from the WSR, especially of young and highly qualified people, an ageing society and increasing social disintegration.

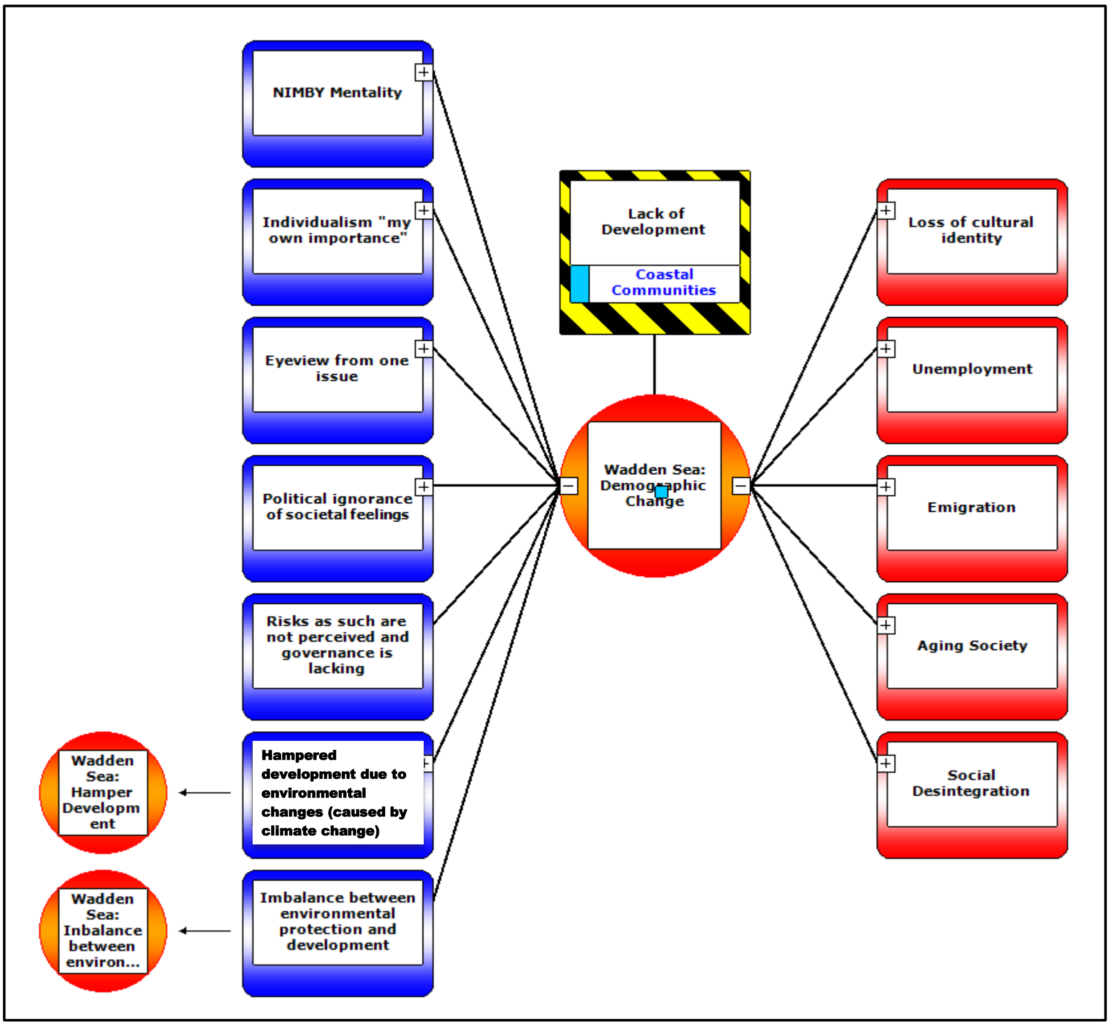

Figure 11 Bow-tie diagram dealing with the stakeholders concerns about demographic changes in the WSR

More than the other two bow-tie diagrams (on environmental change and imbalanced development) this diagram makes clear that we are dealing with different social processes which lead to stagnating development and increasing concerns in coastal communities with respect to demographic change (Figure 12). There are obvious links between the three bow-ties as well as cascading effects: Unless they are managed well, the issues highlighted around the topics of environmental change and imbalanced development will also put pressure on the management of demographic change. Figure 12 presents a diagram overview of the various links and feedbacks.

Especially the bow-tie on demographic change highlights the fact that risk management is more than implementing technical measures. Dealing with social processes is an important part of comprehensive risk management in order to successfully manage risks and uncertainties.

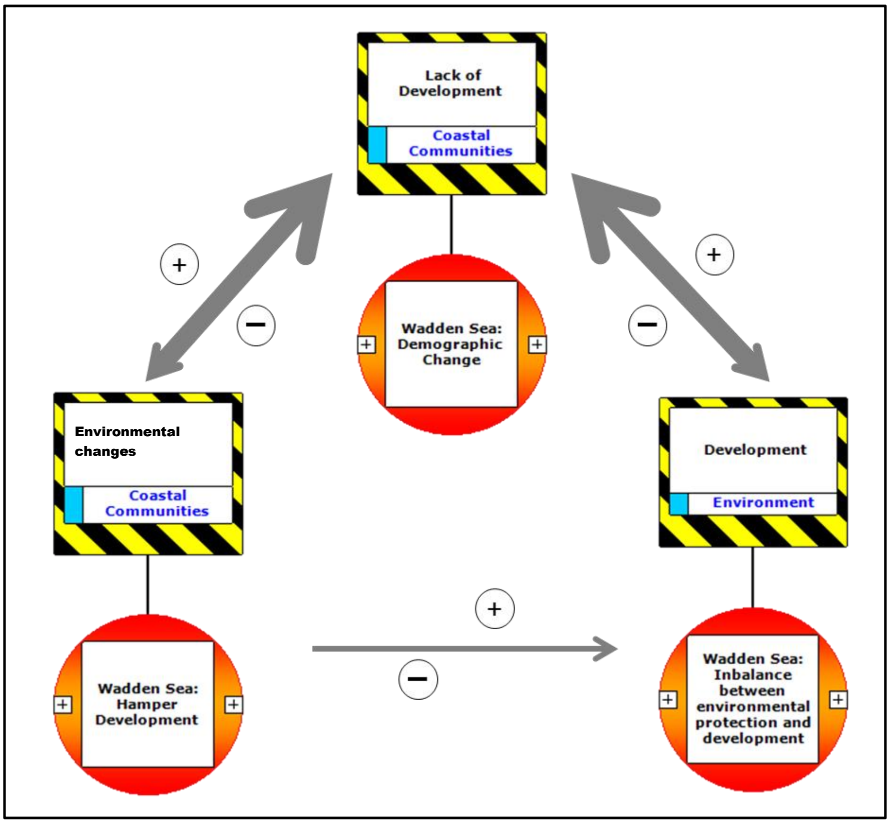

Figure 12 Schematic overview of the interlinkages between the three bow-tie diagrams (each diagram is represented by its central element). The width of the arrow reflects on the influence towards the other thematic element

3.3.2 How to deal with multi-risks? Responsibilities on different scale and different levels

The assessment of the perceived risks was improved by the second participatory workshop with the WSF. The focus of the second workshop was on cooperation and interaction between different actors and stakeholders. The guiding question was: Who is responsible for and engaged in risk management?

This second round of discussion was important as comments and concerns raised during the first workshop could now be linked to the different elements of the bow-tie diagrams. Changes could be added and further concerns and issues could be included. The aim of the second workshop was to fill the different bow-ties and to discuss and validate the perspectives and concerns of the WSF members they presented.

In a second step, a closer look was taken at the processes of risk management processes, in part represented by the measures listed in the bow-ties. The major focus of the small group discussions was on determining current responsibilities and evaluating the level at which current management is performed or should be performed. In general, responsibilities were differentiated into local, district/municipality, national and trilateral/international responsibilities. The discussion made clear that an additional level of responsibility was necessary, since some specific regulations such as the German Länder responsibilities were not reflected. Another outcome of the discussion was the missing responsibility of the economic sector, which was not included in the responsibility structure. The discussion showed that in many cases, risks are dealt with at different level of responsibility – which is necessary so that general aspects and higher level overviews can be included just as much as specific adaptation at the local level. In addition, different administrative structures in the three Wadden Sea countries lead to slightly different allocation of responsibilities in each country. But these differences in administrative structures are not seen as a major problem. The main impediment to successful risk management is lack of communication, mainly between different actors at different levels and representing different sectors. The question was raised which part the trilateral level could play in any future risk management. In general, there are clear signs that multi-stakeholder involvement could be beneficial for dealing with risks and uncertainties in the WSR.

The plenary of the WSF agreed that multi-sector involvement is favoured and that the WSF could provide a platform to raise awareness in the WSR. The Forum itself is already involved in topics such as sustainable management, integrated coastal management and CO_2 reduction schemes. In February 2014, the WSF was assigned a new responsibility, which is to deal with risk management; this means specific tasks and commitments of the WSF need to be established. The results of the second workshop address these issues. Discussions and commitment at the trilateral level could trigger an exchange of experience and get people together to discuss common problems that arise in all three countries. The discussion showed there is support for strengthening the trilateral level in risk management in the WSR. The main benefits of a trilateral approach to risk management are seen in improved communication and exchange of experiences, as well as improved cross-sectoral sensitization of stakeholders towards different coastal risks. A further step will be taken at the next workshop in May 2015.

In order to be successful, the WSF needs the support and commitment of the political level, not only at a regional and local scale but also the national and even European scale. Risk management will become more important in future and existing stakeholder platforms should be used to involve society in political processes. This will lead to more acceptance and trust in political decision making.

More than 10 years ago, the WSF discussed scenarios of socio-economic development in Europe. At that time, almost nobody could imagine a weak Europe. This has changed dramatically in the past few years. Europe needs stakeholder and sector commitment, and MSPs could play an important role in facilitating this.

To summarize, the bow-tie analysis offered a well-structured and plausible overview of the risks that threaten Wadden Sea communities. The (perceived) causes of these risks and the resulting consequences could be teased apart, and their spread across multiple spatial scales and sectors was identified. Impacts and damages affect social, physical and economic structures in a similar way.

The bow-tie on environmental change highlights the fact that measures dealing with the causes of these risks are limited to adaptive measures such as coastal protection measures.

Major challenges, however, arise from the right side of the bow-tie diagram. It becomes obvious that action and improvement is needed in the management of consequences. The bow-tie also shows where improved risk management could be fostered by the MSP.

The bow-tie on demographic change highlights the fact that social causes are at the heart of changing societal structures and composition. The analysis presented here underlines the need to include social processes in integrative risk management.

Apart from offering detailed insights, the bow-tie analysis also illustrates the links between different risks and the interdependencies and feedbacks that exist between them. In the participatory processes, the bow-tie diagram helped to sensitize stakeholders to the fact that effective risk management is a complex, multi-faceted task which requires the involvement of a wide range of actors and sectors. The question of how to deal with these issues is closely linked to the question of who holds what responsibilities and how actors can collaborate effectively across different level. The discussion, facilitated by the bow-tie diagram, highlighted multi-scale and multi-level responsibilities of different sectors and institutions, encompassing national, federal, regional and local levels and different institutions in charge. A major challenge is the fact that the same risk is dealt with by actors with multiple responsibilities at different administrative levels, and that actors at the same level often represent different sectors or fields of interest. There are indications from the collaborative process that WSF members are well aware of the Forum’s capability in this multifaceted setting. Concrete tasks and procedures to implement specific aims will be developed as part of the ongoing cooperation with the ENHANCE project.

4 Conclusions

Risk management is a comprehensive and complex process which clearly extends beyond the mere application of technical measures. More than anything, risk management is a societal process and as such is embedded in historic and cultural settings. Against this background, it is obvious that perceptions and awareness of risks, interests and political will all contribute to shaping the risk management process. Results obtained so far made quite clear that integrative risk management should take these aspects into account.

Risk management is understood as a continuous process comprising risk perception and awareness, as well all elements connected to the risk management cycle (risk analysis, risk assessment, risk evaluation, establishment of strategies and measures, risk monitoring). Integrative risk management therefore has to be understood as a negotiation process of governance which addresses specific needs, objectives and goals and which mediates between different interests in order to meet a commonly accepted safety level.

Risk assessment often relies on economic cost-benefit analysis which allows potential risks to be expressed in monetary terms. This usually leads to management measures designed to reduce the expected economic losses. In the opinion of the authors, this is a short-sighted view. A multi-stakeholder partnership (MSP) for cross-sectoral and transnational risk management requires a more holistic view, taking into account not only economic aspects, but also perceptions of risks and societal behaviour.

Applying purely quantitative approaches in risk governance has some weaknesses as these approaches are highly sensitive to the availability of data and computing time. Nevertheless, quantitative risk assessment approaches can provide some guiding values for current and projected future situations, and can provide a good scientific basis for an open participatory process. The results of quantitative approaches are helpful in broad discussions and decision-making processes.

Based on the conceptual framework of integrative risk management, it is obvious that risk assessment not only includes the assessment of hazards, their causes and consequences from a scientific point of view, but also from the perspective of society. In Case Study 3, a risk assessment was carried out in a participatory process involving stakeholders and communities. Assessing the basic structural elements of risks – the threats, their causes and their consequences - is part of a wider social process and as such is influenced by competing interests and structured by multi-level responsibilities, taking into account different concerns, interests and rationalities.

Risk assessment in the Wadden Sea Region (WSR) includes a combination of quantitative and qualitative approaches, using the strengths of both. Four methods were employed to assess risks to society:
i) causes of storms surges were assessed quantitatively with the help of climate scenarios and flood maps;

ii) consequences (impacts) of storm surges were assessed quantitatively by a comprehensive state-of-the-art desktop study on storm surge damage modelling,
iii) consequences of storm surges were assessed qualitatively by means of a perception study based on an online survey,
iv) causes, consequences and their interlinkages, as well as interconnections between different risks in the WSR, were analysed by means of a bow-tie analysis.

This combined approach enables to answer the central questions raised at the outset:
Which historic experiences exist in the WSR, and how has society traditionally handled crisis situations?
Current approaches to managing storm surge risks are shaped by a long-standing tradition of dealing with these risks in the WSR. Both the participatory workshops and the online survey showed deep-seated trust in hard engineering as the traditional method of storm surge management. There is consensus that storm surges pose a major risk to Wadden Sea communities, and that traditional engineering measures will represent an adequate defence against disastrous storm surge events in the decades to come. There is no doubt that structural coastal protection measures are an important element in storm surge management, a fact underlined by the desktop study on storm surge damage modelling in the WSR. All of the models reviewed base their calculations on an estimate of the likely success or failure of hard protection measures. Most studies then conclude that hard coastal defences should be strengthened in order to avoid the monetary damages calculated by the model.

Which risks are we prepared to take?
As described above, society in the WSR is willing to live with and handle the risks of storm surges. For the time being, and for the next decades, the communities in the WSR feel well prepared for this due to existing coastal protection measures. But the WSR is not only exposed to storm surge risks. The risk assessment clearly highlighted the importance of other risks related to climate change. Perceived risks also include an imbalance between the interests of nature conservation and social and economic development, as well as risks related to demographic change. For these issues stakeholders perceive an urgent need for action. The bow-tie analysis highlighted the strong interdependencies between all of these risks. The complexity of the risks identified demands their integrative management, taking into account the causal relationships between these risks.

Which consequences are we prepared to deal with? And which risks are perceived as priority risks and identified as action points for risk management?
The risk assessment in the WSR highlights that management of the causes of storm surge risks is restricted by climatic and topographic boundaries. Existing coastal protection measures designed to deal with the causes work properly. The consequences of storm surges pose much greater challenges than the causes, both under current climate conditions and even more so in the future due to climate change. Impacts will occur in different sectors and at different levels and affect the economic, the social and the environmental sphere. It follows that enhanced (storm surge) risk management in the WSR has to focus on the consequences of storm surges if society's capability of mitigating and successfully lowering these risks is to be improved. Stakeholders along the Wadden Sea coast of Schleswig-

Holstein (results of the online survey) are mainly concerned about impairments of living conditions including financial penalties as a consequence of storm surge events.

Damage modelling could facilitate the decision-making process by showing what economic consequences could be expected in the case of storm surge events. However, modelling results differ because of different projections, specific boundary conditions, data sets and levels of detail defined in each project. In the end, these results can merely support the essential negotiation process surrounding the risks to be taken by society. Results from Case Study 3 make clear that adaptive measures to protect against storm surges are well established, however, the Wadden Sea community feels less prepared to deal with the consequences. Improvement is necessary with regard to mitigating measures and to a more participatory and collaborative process.

The bow-tie analysis highlighted further major challenges in the multi-risk area of the WSR. The discussion on demographic change clearly showed that changes in the structure and composition of society present major challenges to future integrative risk management. The causes for these situations lie in social processes. The analysis presented in this report underlines the urgent need to include social processes in risk management in order to successfully manage future risks and uncertainties.

Based on the combination of quantitative and qualitative approaches, the case study was able to answer the main questions related to risk assessment in the WSR. But what does the risk assessment imply for the MSP envisaged in the WSR to enhance (storm surge) risk management? Carrying out risk assessments as a collaborative and participatory process facilitates awareness rising in the WSR and underlines that risk management is not only a technical process but a social negotiation process. Stakeholders have concerns with respect to the consequences of storm surges, gaps in current storm surge risk management, and their involvement in storm surge risk management. These concerns set the scene for further negotiation processes, leading to improved strategies, measures or processes of rethinking storm surge risk management along the Wadden Sea coast. The foundation is laid for an MSP in the form of a permanent stakeholder forum dealing with risk assessment in the WSR.

Case Study 3 contributes to the discussion on MSP as an effective approach to enhancing risk management of natural hazard events in the ENHANCE project. It can make suggestions with respect to analysing the development and performance of MSPs, including the processes and roles of stakeholders. It is also the aim to initiate new paths of thought about integrated risk management in the WSR together with the stakeholders and institutions represented in the WSF, taking account of their role as multipliers in the public, private and civil sector.

In a next step the case study will focus on the organizational structure in multi-stakeholder risk management in a cross-border region. The results will be part of further ENHANCE deliverables that pick up the description of MSPs and disaster resilience schemes as central elements.

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ANNEX A – Results of the conducted desktop study storm surge damage modelling

Appendix A Table 1 Results of the desktop study about state-of-the-art in storm surge damage modelling focusing on research results for the Wadden Sea Region

Project name	Subproject / case study	Responsible institution / Person in charge	Year / period	Region	Short description of the project	Methodological approach	Data	Damage estimation
ComRisk - Common Strategies to Reduce the Risk of Storm Floods in Coastal Lowlands	Subproject 6 - Flood Risk in Flanders/Zeeuws-Vlaanderen	The Coastal Division of the Flemish Community leads the subproject about the Flood Risk in the cross boundary area Flanders-Zeeuws-Vlaanderen. The study is carried out by the Consultant IMDC and advisers. The calculation of damage in the Netherlands was carried out by "Rijkswaterstaat" (DWW). A steering committee was established to guide and discuss the results. The committee consists of governmental organizations of Flanders (Coastal Division and Flanders Hydraulic Research) and the Netherlands (Rijkswaterstaat, the province and the polder board) (COMRISK 2005a, p.1)	2002 to 2005	Vlaanderen (B) und Zeeuw-Vlaanderen (NL); The coastal lowlands of the Belgian region Vlaanderen and the Dutch region Zeeuws-Vlaanderen constitute a single cross-border coastal flood unit with a length along the coastline of 25 km and an landwardth width of 15 km (Verwaest & Trouw 2005, p. 2)	The study of flood risks in Flanders and Zeeuws-Vlaanderen (Dutch name) resulting from possible failures in the sea defence structures between Zeebrugge and Breskens (COMRISK 2005a, p.1)	The risk assessment method consisted of calculating the expected consequences for a limited number of representative storm events associated with a certain return period. Each of these representative storm events is taken to represent a cluster of possible storms, so that all clusters together represent all possible storm events. Hydrometeorological characteristics are assumed to be comparable for all storm events within the same cluster. The annual risk was calculated as a weighted sum of the probabilities times the consequences for the representative events. Thus the integration over all possible extreme events is discretised as a summation of a limited number of representative events. In this case study 4 representative events were defined, with characteristic return periods 1.000 years, 4.000 years, 10.000 years and 40.000 years. Expected values of the 4 consequences were calculated for each of these. Risk is calculated as a summation for the 4 events of the product of damage and probability. By choosing this risk assessment method we assured that the results of the calculation provided information not only on the risk but also on the return periods of coastal flooding consequences (Verwaest & Trouw 2005, p. 3). To calculate the consequences of flooding, the method developed by Flanders Hydraulics Research is used for Vlaanderen, and the method of Rijkswaterstaat (Directorate General of public works and Water management, the Netherlands) is used for the Netherlands. The two methods are similar. Direct economic damage and human casualties are considered as the consequences of a flooding event. Thus significant consequences are not taken into account, e.g., damage to nature, psychological damage, damage to the economy outside the flooded area. The methods are based on a GIS-approach. The maximum damage per cell is determined on the basis of land-use maps and information obtained from the National Bureau of Statistics. The damage in the area is then calculated for each category of damage (housing, possessions, agriculture, industry) based on damage functions. Damage functions represent the development of the damage as a function of the depth of inundation, and replacement values or maximum damage values for these categories. This can be done for all potential damage categories. Combining the two sets of data produces the damage per cell. A similar method is used for casualties, with the difference that the maximum rise velocity (Vlaanderen) or the maximum horizontal velocity (the Netherlands) is also used as an input parameter (Verwaest & Trouw 2005, p. 7).	Damage functions and maximum damage: To make the land use maps, CORINE Land Cover land use file was used (with a resolution of 30*30 metres) as well as the Small-scale land use file for Flanders and Brussels (with a resolution of 20*20 metres). Both files are combined, keeping the advantages of the various files. 15 different categories can be distinguished: Buildings I, II and III; Infrastructure I and II; Industry I and II; Airport I and II; Recreation; Arable farming; Pasture; Forest; Water For roads and railways, a separate GIS database (top50v) is used, to assess the damage. The following choices have been made to to compile the collection of damage functions: 1) a distinction is made between the damage due to fresh and salt water floods (not in the Netherlands) 2) the maximum damage amounts are based on the replacement value. When using the replacement value as basis for the maximum damage amount, it is assumed that an 'identical' object can be obtained. A 6-year-old car is replaced with an 'identical' 6-year-old car. 3) no distinction is made between high- and low-frequency flooded areas. 4) the damage is determined by the (maximum) water depth. Damage calculation method The general expression used to determine damage due to floods is (Vrisou van Eck et al 1999, see COMRISK 2005a p. 178)	The calculated damages and casualties for the different representative events ar shown respectively in Table 1 + 2. Total economic damage range from 5.000.000 € - 1.000.000.000€ (Verwaest & Trouw 2005, p. 7-8). Damage to industry: The maximum (direct) damage per employee amounts to € 175820. The maximum (direct) damage according to the method depending on the surface area is € 96.2267 / m². Damage to Infrastructure and airport: The maximum direct damage in Flanders is € 96.2267 / m² everywhere. There is no indirect damage. For damage to recreation, the maximum damage is used as described in Vanneuville et al. (2003a, p. 9). This is € 0.054 / m² everywhere in Flanders. Damage to Orchards, arable farming and meadow: It is equal to twice the maximum damage with a fresh water flood plus a fixed amount of € 0.05 / m² (COMRISK 2005a, p. 180). The maximum damage for arable farming thus depends on the agricultural region (Vanneuville et al. 2004: addendum B), the maximum damage for pasture is equal to € 0.146 / m² + € 0.05 / m². The damage functions and the indirect damage (10% of the direct damage) are identical to those of salt water and are described in Vanneuville et al. (2002, p. 26, 32-33). For orchards the damage function is equal to the damage function for arable farming, but the maximum damage differs. In the "Damage functions for forests and orchards" (Vanneuville et al. 2004: addendum C) note, a price of € 2.96 /m² + € 0.05 / m² for the addition of lime is determined for a salt water flood (COMRISK 2005a, p. 181). To determine the number of vehicles, the most recent available data are used on the level of the statistical sector, i.e. the census of 1991. The vehicles aggregated to municipality level. The value of the vehicles is the value calculated in Vanneuville et al. (2002), i.e. € 4627 per vehicle. The vehicles are distributed homogeneously over the "Buildings I, II, III", "Industry I, II" and "Infrastructure I, II" categories (COMRISK 2005a, p. 181).
	Subproject SP 7 - Risk Assessment for the Wadden Sea	The Danish Coastal Authority (DCA)	2003 to 2004	Ribe (DK), Danish Wadden Sea Coast	The study has been performed in two major steps which comprises (I) the hazard analysis (calculation of the overall flooding probability) and the (II) the vulnerability analysis evaluating the expected consequences of flooding (Pintkowitz, Kortenhaus & Oumeraci 2005, p.2). Hazard analysis with ProDeich model + Vulnerability analysis (report chapter 5, pp. 84) including valuation analysis and damage analysis.	For the deterministic and probabilistic calculations within the hazard analysis, the model by Kortenhaus (2003) for sea dikes has been used. It comprises 25 failure mechanisms with a total number of 87 input parameters. The input parameters were grouped into parameters describing (I) the geometry of the structure, (II) the hydromechanics boundary conditions, and (III) the geotechnical properties of the structure (Pintkowitz, Kortenhaus & Oumeraci 2005, p.2). As cartographic basis for the vulnerability analysis, altitude data in a grid net of 25x25 metres was used to generate a topographical map of the flood-prone area, being delimited by the 5.0 m DVR90 altitude line. The altitude data was supplemented by altitude data from road surveys Pintkowitz, Kortenhaus & Oumeraci 2005, p.10). Within the flood-prone area of Ribe six categories of direct, tangible damage were selected (buildings, movable property, agricultural acreage, livestock, electric installations, traffic system). Additionally, four damage categories (inhabitants, employees, vehicles, tourism) subject to intangible, direct/indirect damage were considered in a descriptive form (Pintkowitz, Kortenhaus & Oumeraci 2005, p.10)	Within this study the following risk elements of direct, tangible damage have been chosen: • Buildings, including residential buildings, agricultural buildings and industrial buildings; • Movable property, including movable property in residential, agricultural and industrial buildings; • Agricultural acreage, crops; • Livestock; • Electric installations (pumps, windmills); • Traffic system (roads, railways). As intangible, direct/indirect damage categories, the following risk elements are only considered in a descriptive form in Chapter 5.3: • Inhabitants; • Employees; • Vehicles; • Tourism. (COMRISK 2004, p. 88) Typically, data was available at national registers, such as the Building and Housing register or the Central Livestock register. In other cases, data was provided by research centres or the responsible county. The request of data from national registers or public administrations about the damage categories showed however clear differences in data quality and format. This fact complicated the procedure of geocoding each risk element by means of a GIS software application (Pintkowitz, Kortenhaus & Oumeraci 2005, p.10). Furthermore, a mean value per car of 300.000 DKr. (€ 40.200) is defined (COMRISK 2004, p. 92)	Due to differences in inundation behaviour, damage within each scenario varies between 1.15 and 424.5 million DKK (56.9 million €). Only the scenarios Sc5 and Sc6 resulted in damage exceeding 100 million DKK (13.4 million €). The scenarios Sc1, Sc2 and Sc7 showed comparable inundation behaviour and resulted in the 12 same total damage for all three scenarios. Tab. 5 gives the final results of the calculated damage for the seven scenarios (Pintkowitz, Kortenhaus & Oumeraci 2005, p.11)

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	Subprobject SP 8 - Risk Assessment for the Lincolnshire Coast Flood Unit	Halcrow Group Limited and Risk & Policy Analysts Ltd (RPA)		24 km of the Lincolnshire coastline between Mablethorpe and Skegness, referred to as Lincshore coastline (UK)	The subproject ‚Risk Assessment in Lincolnshire‘ has been undertaken jointly by Halcrow and RPA and examines appropriate methods of carrying out risk assessments at each spatial scale, to develop coherent spatial strategies to manage flooding risk at regional, area and individual scheme scales. It does this through: Application of jointly developed risk assessment framework for a scheme and strategy ‚nested‘ within a region; Undertaking a state of the art risk assessment for this flood unit; Recommendations for measures to reduce the risk of flooding (increase the safety standard); Demonstration and dissemination of good practice of risk assessment within strategy planning. (COMRISK 2004; Final Report SP 8, S.5)	The Lincshore defence strategy is based on the maintenance of a design beach profile. By taking a simplified relationship between the design minimum berm width and the level of storm resistance (and, hence probability of flooding), it has been possible to show how risk-based approaches based on risks to people, risks to assets (mainly property damage) and risks to both people and assets can be developed. There are numerous ways in which the effects of flooding can be ‘measured’. Within the UK, great reliance is placed upon extensive modelling to generate flood depths which, in turn, are used to generate estimates of losses in monetary terms. In this case study, the much simpler approach of simply counting people in flood compartments close to the defences yielded similar minimum berm width requirements. Broader examination has been made of flooding from one of the coastal zones to demonstrate how a desk-top tool could be generated to assist in the identification of optimal areas for the placement of recharge during the decision making process. Analysis to examine the effects of a range of profile variations on the resulting overtopping volumes and consequent flood areas, depths and hence damages has been used to generate a limited range of data and look-up tables for interpolation. Limitations, issues encountered and recommendations for development of similar approaches in the future have been identified (COMRISK 2004, p. 1).	Much of the data used and statements contained herein are taken from the latest Strategy Revier (Halcrow 2003/2004) (COMRISK 2004; Final Report SP 8, S.5)	Valuation of Assets at Risk: In the Strategy Review (Appendix H - Economic Appraisal), the area at risk is divided into over 100 „flood reservoirs“ with assets defined for each reservoir. The overall values are presented in Table 4.1. (Residential Properties, Number over 27.000, Capital Value approx 2 bn GBP; Caravans, over 19.000, Capital Value approx 70 m GBP; Industrial/Commercial Properties, over 3.500, Capital Value approx 320 m GBP; Farmland over 33,000 ha, Capital Value approx 70 m GBP) (COMRISK 2004; Final Report SP 8, S.5)
	Subproject SP 9 - Pilot Study Langeoog	Niedersächsischen Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (Coastal protection agency of Lower Saxony)	2005	Island of Langeoog	The following main issues shall be investigated within the subproject: an integral inventory of physical and socio-economic conditions as well as existing coastal defiance measures in the Langeoog flood unit; a state of the art risk assessment for this flood unit; recommendations for measures to reduce the risk of flooding (increase the safety standard) (COMRISK 2005b, p.2)	Hazard Analysis: A statistical analysis is used to determine certain exceedance probabilities of surge water levels. Where the coastal defiance system consists if dunes, a two dimensional numerical model simulate beach and dune erosion is used. The model provides among other the potential erosion volume and the post-storm beach and dune shape. For the parts of the coastal defiance system consisting of dykes, a deterministic calculation of failure is executed. The ProDeich model which contains functions for several failure modes for dykes is applied (COMRISK 2005b, p. 9) .Vulnerability analysis: A valuation analysis and a vulnerability analysis for the protected area including the village Langeoog is executed on a micro scale level. These analysis-methods are based on the results of the MERK-project. With the Merk report a valuation and a damage estimation approach is available, which is evaluated and documented. A micro scale approach is necessary to depict the situation for the relative small investigation area of Langeoog (COMRISK 2005b, p.10). To determine the vulnerability, detailed information concerning water propagation and water depth are needed. Therefore hydraulic calculations of water inflow at detected failure locations are carried out. In combination with a GIS-based water level-approach a high accuracy digital elevation model the water depth is determined for each element at risk. The approach of depth-damage functions offers the opportunity to estimate the degree of expected damage for each element. In combination with the valuation analysis the expected damage can be expressed as a monetary value. The effects of drinking water supply by a salt water intrusion in the fresh water lens due to partly flooding of the catchment area of the wells in case of a dune breach is analyzed on basis of numerical simulations. The vulnerability for given scenarios is estimated by an expert statement on the water board OOWV on basis of salt concentration in the extracted freshwater of several wells determined by means of a numerical model (COMRISK 2005b, p.11).	The assessment of the damage potential requires several procedures and different sources of information. The project structure is represented in figure 4-2 (COMRISK 2005b, p. 45): processing, modification and actualization of the digital data; demarcation of the study area; field work; GIS and data integration (COMRISK 2005b, p.45). Valuation analysis: On the basis of the methodology, developed in the project MERK, the different damage categories are evaluated. Guest beds, jobs, inhabitants are only recorded quantitatively (intangible values). The other objects are defined as tangible values and can be assessed monetarily: buildings, building inventory (households effects), real estate values, motor vehicles, traffic areas, agricultural land, livestock assets, forest land, recreational land, gross value added, fixed assets, stock value (COMRISK 2005b, p.46).	According to the requirements of the contractor the damage potential is only represented for the terrain heights up to 5.5 m above sea level. Judging from historical storm surges and taking the sea level rise into account, this high zone can be classified as flood prone area. In order to complete the results and present on an overview of the total area, the values of the zone above 5.5 m ask are illustrated additionally. 85.5% of the total values are located in areas up to 5.5 m ask. The results up to the 5 m contour line allow a comparison with the damage potential of the area analysed within the MERK-project. Total value up to 19.5m above sea level: 1.115.893.800 €; total values up to 5.5 m above sea level: 931.522.000€; total values up to 5.0 m above sea level: 864.209.900€ (COMRISK 2005b, p.57). In case of flooding all production wells, whose buildings (well-shaft, electrical installation) would come directly into contact with the seawater, would be temporarily closed to protect the plans as well as to avoid a possible pollution during flooding. The measures of the restarting extraction depend on the extent of the damage. Assuming that well-shaft is flooded, the coasts of cleaning, disinfection of extraction well, pumping test, renewal of the electrical installation are estimated up to a height of 25.000€ for each well. Some of the wells are not secured against lift. Thereby the coasts of the building of a new well-shaft could increase around approx. 20.000€ for each well. (COMRISK 2005b, p.58). The damage potential on the well fields is estimated to a maximal amount of 45.000€ per affected well. There are 16 production wells situated in the Pirola valley and the adjacent valley. The maximum damage potential is there with calculated with 720.000€ (COMRISK 2005b, p.59).

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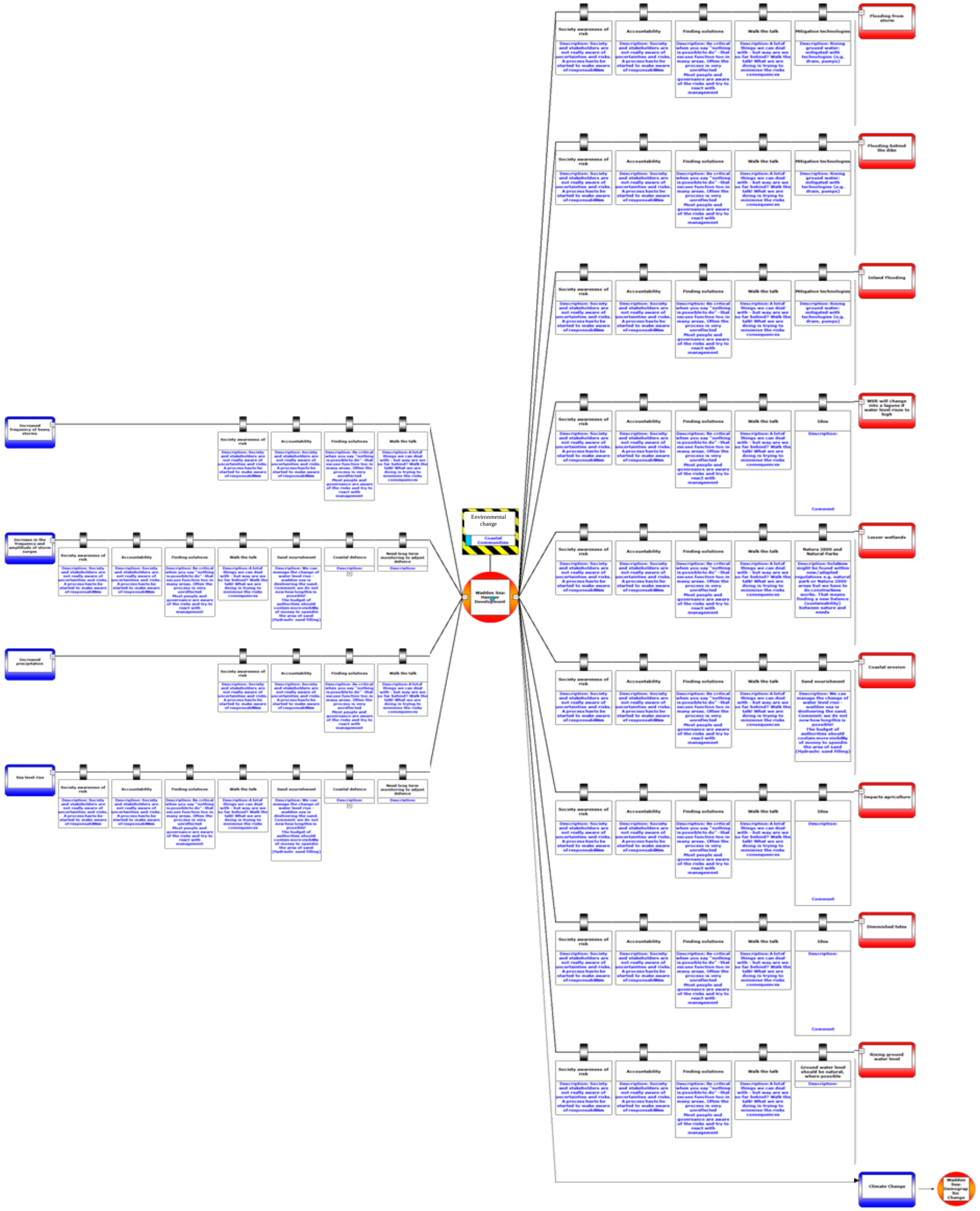
FLORIS - Flood Risks and Safety in the Netherlands		Ministerie van Verkeer en Waterstaat	2001-2005	16 dike ring areas in the Netherlands	The purpose of the Floris project is to gain an understanding of the consequences and the probability of flooding in the Netherlands (FMinisterie van Verkeer en Waterstaat 2005, p. 7). To achieve the stated goals four routes were set out within Floris project, i.e.: 1. determining the probability of flooding for 16 dike ring areas; 2. gaining an understanding of the problems affecting hydraulic structures; 3. gaining an understanding of the possible consequences of flooding; 4. presenting a picture of the order of various types of uncertainties and how to deal with them (Ministerie van Verkeer en Waterstaat 2005, p. 17).	To determine the consequences of flooding the Floris project focused on determining the number of victims, the economic damage and damage to the landscape, wildlife and cultural heritage (natural features). It is difficult to validate what is known about determining these effects, particularly as there is also so little practical data available. The methods for determining the effects of a flood are therefore largely based on the experience of the flood disaster in 1953 and experience from abroad. In the Floris project major advances have been made in defining the possibility of evacuation (new evacuation module: how quickly a population can be evacuated) and possible flooding scenarios (how and how quickly the water flows into the dike ring and what depth of inundation occurs as a result). On the basis of these scenarios the number of victims and the economic damage can be determined (Ministerie van Verkeer en Waterstaat 2005, p. 21). The HIS Schade en Slachtoffermodule [HIS Damage and Victim Module] (version 2.1), was used for this in the Floris project. HIS stands for High water Information System (Huizinga et al., 2004). The damage is determined for each location on the basis of the land use and a damage function (Ministerie van Verkeer en Waterstaat 2005, p. 25). In four steps: 1. Determining the flooding scenario: the inundation depth is needed as input, and this can be found from a flooding scenario taken from the global approach described above or from the detailed approach; 2. Determining the land use: the various forms of land use throughout the Netherlands are available in the form of a map; 3. Defining the damage functions for all types of land use. Each damage function consists of a maximum damage sum and a damage factor. The maximum damage amount is the maximum damage which can occur in a flooding scenario and is based on the replacement value. The damage factor is a figure between 0 and 1 and is a function of the inundation depth and the current velocity; 4. The damage is calculated by combining the inundation depth, current velocity and the damage function for each land use form in a mathematical unit (Ministerie van Verkeer en Waterstaat 2005, p. 25f).		When determining the damage a distinction is made between three different categories of damage: 1. Direct damage – material; Direct material damage refers to the damage which is caused to objects, capital goods and movable goods as a result of direct contact with water. This includes: x Cost of damage repair to immovable property (land and buildings) rented or in ownership: land and buildings; x Cost of damage repair to means of productions, such as machinery, equipment, process plant and means of transport; x Damage to property contents; x Damage due to the loss of moveable property, such as raw materials, auxiliary materials and products (including damage to harvest). 2. Direct damage - due to business interruption; The second category of direct damage is defined as damage due to business interruption, i.e. the commercial losses caused by lost production. 3. Indirect damage. The indirect damage comprises the damage to business suppliers and customers outside the flooded area and travel time losses due to inoperability of roads and railways in the flooded area (Ministerie van Verkeer en Waterstaat 2005, p. 26). The average economic damage in the different flood scenarios: Noordoostpolder 1,900 million €; Zuid-Holland 5,800 million €; Land van Heusden /De Maaskant 3,700 million € (Ministerie van Verkeer en Waterstaat 2005, p. 58). The economic risks in the present situation are approx. € 2 million per year for both Zuid-Holland and the Noordoostpolder. For dike ring 36 Land van Heusden/De Maaskant the economic risk is more than a factor 10 greater, i.e. approx. € 37 million per year. x The upper limit of the damage range for the Noordoostpolder amounts to € 4200 million and € 7500 million for Land van Heusden/De Maaskant. This amount is much higher for ZuidHolland: € 37,000 million. The number of victims for ZuidHolland may also be higher than for the other two dike rings. Particularly with multiple breaches from the coast large areas with many inhabitants could be inundated. x The probability of flooding for dike ring 14 Zuid-Holland is relatively small: approx. 1/2500 per year. The most significant mechanisms here are dune erosion, uplifting and piping of one dike section and the reliability of the closing procedures of some hydraulic structures. For dike ring 7 Noordoostpolder the probability of flooding amounts to 1/900 per year and here the most significant mechanism is structural failure of two hydraulic structures. For dike ring 36 Land van Heusden/De Maaskant, the mechanism of uplifting and piping, the non-closure of two hydraulic structures and insufficient defensive height of a tidal lock contribute the most to the probability of flooding. x From research it appears that only to a limited extent is it possible to predict well in advance flooding from the sea or a lake such as at dike ring 7 Noordoostpolder and dike ring 14 Zuid Holland. The failure mechanism uplifting and piping is also almost impossible to predict, such that in the present situation it would be difficult to arrange preventive evacuation for dike ring 36 Land van Heusden/De Maaskant (Ministerie van Verkeer en Waterstaat 2005, p. 58).
HoRisK - Hochwasserrisikomanagement für den Küstenraum (Flood risk managemet for coastal areas)		Loint project of RWTH Aachen,University of Rostock, Niedersächsischen Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (Coastal protection agency of Lower Saxony)	2009 to 2013	German North and Baltic Sea Coast	It is the aim to develop coastal protection methods and approaches to practical damage modelling and development of risk analysis as basis for flood maps and flood risk maps as well as flood risk management plans. These analysis should be built on existing data sources in coastal protection. The developed approaches are applied for selected pilot case study areas along the German North and Baltic Sea Coast. Methods developed in this project could provide a basic for the implementation of the EU Flood Risk Directive along the German North and Baltic Sea Coast.			
	HoRisk A - Failure of coastal protection facilities and damages	RWTH Aachen	2009 to 2013	Selected pilot case study areas along the German North and Baltic Sea Coast of Lower Saxony, Schleswig-Holstein and Mecklenburg-Vorpommern	Within the project all modules of damage as well as risk analysis are performed with regard to the aim of the project. The project focuses on the detailed analysis of damage and risk analysis to fill existing knowledge gaps. Additional modules were conducted by a literature study. In the following step, practical application is conducted for selected coastal pilot study areas.	Literature research, expert interviews on effects of level of salinity on different risk elements (Schüttrumpf et al. 2013)		Estimation of losses due to crop loss for different species in different producing areas, e.g. winter wheat in Marsh and Geest areas (1.690,28 €/ha (marsh) bzw. 1.326,56 €/ha (geest) (Schüttrumpf et al. 2013,p.71) taking into account two different scenarios. Scenario 1: total loss of crops in the first year. Scenario 2: Total loss of crops in the first year as well as partial losses in the following years on the impermeable study areas (Schüttrumpf et al. 2013, p. 73). Study area Norden on marsh land / yield power "high": Total damage scenario 1: 28.262.704€ , Total damage scenario 2: 36.648.235€ (Schüttrumpf et al. 2013, p. 74-75). Study area Norden: Geest/ yield power "low": scenario 1 total damage: 10.724.049€

Project name	Subproject / case study	Responsible institution / Person in charge	Year / period	Region	Short description of the project	Methodological approach	Data	Damage estimation
	HoRisk C - Consequences from failure of coastal protection facilities in the area of the North Sea Coast and minimizing the damages	Niedersächsischen Landesbetrieb für Wasserwirtschaft, Küsten- und Naturschutz (Coastal protection agency of Lower Saxony)	2009 to 2013	City of Norden (Germany)	It is the aim to develop coastal protection methods and approaches to practical damage modelling and development of risk analysis as basis for flood maps and flood risk maps as well as flood risk management plans. Aim of the subproject is the estimation of efficiency of different coastal protection measures, their level of safety and the spatial distribution of a flooding event due to a failure. Important impact factors are the single coastal protection facilities, the process of different failure scenarios as well as the hinterland topography. An additional focus lies on the improvement of tools to analyse the damage potential, research on additional possibilities to minimize the damage and the risks, applied for selected pilot case studies.	Analysis of the damage is based on the damage potential. Damage potential includes good and values that are potentially stored in the research area , including their spatial distribution. The relative and total loss results from the overall view of the affected area. The degree of damage in general is conducted by specific damage functions. Mainly the damage factor is related to the inundation depth, partly from the storage period of the water in the region as well as the velocity of the water. Moreover the maximum extend of flooded area is important for the analysis. Practically a 1d/2d model is used to calculate these parameters. Therefore, a digital terrain model builds the basis for the tidal water level (Lambrecht et al. 2014). Mesoscale analysis of the damage is performed based on the method I of Meyer (2005). Using this method, potentially affected areas are estimated based on different approaches. Flood damages can be estimated by three categories (direct/indirect; tangible/intangible; primary/secondary) (Lambrecht et al. 2014, p. 66)	Damage identification: conducted based on the method I of Meyer (2005). A very detailed identification of values and damage potentials based on high level, local data (for a comprehensive overview see Meyer 2005; Schüttrumpf et al. 2013;) Spatial mapping of damages: for spatial modelling Meyer (2005) uses land use data based on the digital terrain model (DLM) from the German ATKIS system. Land use data are structured in different levels based on a catalogue of categories. Within the SAFECOAST project changes and improvement of Meyer's technique is applied. These changes are included in the damage estimation of the HoRisK Project. Moreover, changes in economic branches of trade are adapted (Lambrecht et al. 2014,p. 68).	Scenario I: total damage 275 Mio.€; Scenario II total damage 738 Mio.€ Scenario I and II includes as well agricultural damages (scenario I, agricultural losses case I = 12 Mio.€ / case II =15 Mio. €) (scenario II/ case I = 32 Mio.€/case II = 40 Mio.€) (Thorenz 2014, p.81). For scenario III and IV no agricultural losses are included. Scenario III includes a dike foreland of a width of 100 m and a height of NHN + 2,22 m, meaning 0,75 m above mid tidal high waters (Thorenz 2014, p.81). Scenario III mentioned a sum of damage of ca. 64 Mio. € compared to ca. 275 Mio.€ for the scenario without the dike foreland (Thorenz 2014, p.82). Scenario IV includes a sommer dike: the result shows that the maximum extend of the flooded area compared to a scenario without a summer dike decreases about 89% . The average of maximum inundation depth decrease by 45% ; based on this result the total sum of damages decreased from 275 Mio. € to ca. 33 Mio. € (Thorenz 2014, P.83). Compared to scenario I, which included break lines, an additional model without these break lines: the estimated damage of the latter scenario (ca. 289 Mio.€) is approximately 5 % higher than the reference scenario including the break lines. Scenario VIa and Scenario VIb conduct the influence of surface roughness on damages by including different kind of dike breaches and compare the results to each other. Estimated damages vary with regard to different type and extend of dike beaches from 75 Mio € to 309 Mio € (Thorenz 2014).
				Island of Wangerooge			Based on statistical data and land use data of the ATKIS object catalogue existing values and their spatial distribution are calculated for the island of Wangerooge (Lambrecht et al. 2014, p. 93).	The general part of the damage potential exists at a range of 101 €/m2 up to 300 €/m2. However, there are area that potential values reach an extend of up to 900 €/m2. This situation often affects areas of mixed used including residential buildings as well as industrial or economic used areas. Moreover, the importance of touristic use have to be considered for the area of Wangerooge; but the applied method is still not able to consider the current touristic use of the are in a appropriate way (Lambrecht et al. 2014,p. 94). The damage potential for agricultural use in scenario I has a Maximum of 0,09 €/m2. In scenario II maximum values range at 0,11 €/m2. The total sum of damage potentials, considering the whole island of Wangerooge, is approximately 210 Mio. €. Total damage potential due to 0,263 Mio. €/ha (Lambrecht et al. 2014, p. 93). Bringing 5 dike breaches together in one scanrio a total amount of damages of 23 Mio. € is assumed (Lambrecht et al. 2014, p. 97).
MERK - Mikroskalige Evaluation der Risiken in überflutungsgefährdeten Küstenniederungen (Mirco scale Evaluation of risks in floodprone coastal low-lands)		Forschungs- und Technologiezentrum Westküste (FTZ); University of Kiel	2000 to 2002	micro sale risk evaluation in selected coastal low-land areas along the German North and Balitc Sea coasts. Peter-Ording, Kaiser-Wilhelm-Koog (North Sea Coast) Timmendorfer Strand / Scharbeutz, Fehmarn und Kiel (Baltic Sea coast)	Within the project different modules of damage and risk analyses are conducted to fulfil the aim of the project. The focus lies on the in depth analysis of damage and risk analysis.	Risk analysis includes hazard analysis as well as the vulnerability analysis. Hazard analysis specifically analysis the storm surge events based on different overflow and failure scenarios. Modelling these extreme events as well as estimations of the failure scenarios includes hydrological and morphological conditions as well as the existing coastal protection measures. The vulnerability analysis evaluate the expected damages of different storm surge events. The vulnerability analysis is separated into one step of estimating the values and a damage calculation. In order to conduct a spatial distribution of damage in the area, GIS -based raster approaches are established. But due to the fact, that goods and vales could be affected by a flood events but this impact does not automatically result in a total loss, the potential of damages could not be conducted as a dimension to estimate the damages. Resultant to that, monetary damage estimation is evaluated for each scenario. Due to the fact, that for most of the study areas no data exists, interviews on household level had been conducted. The results were discussed within a Delphi-survey. Risk estimation is based on these results for quantitative and qualitative approaches.		

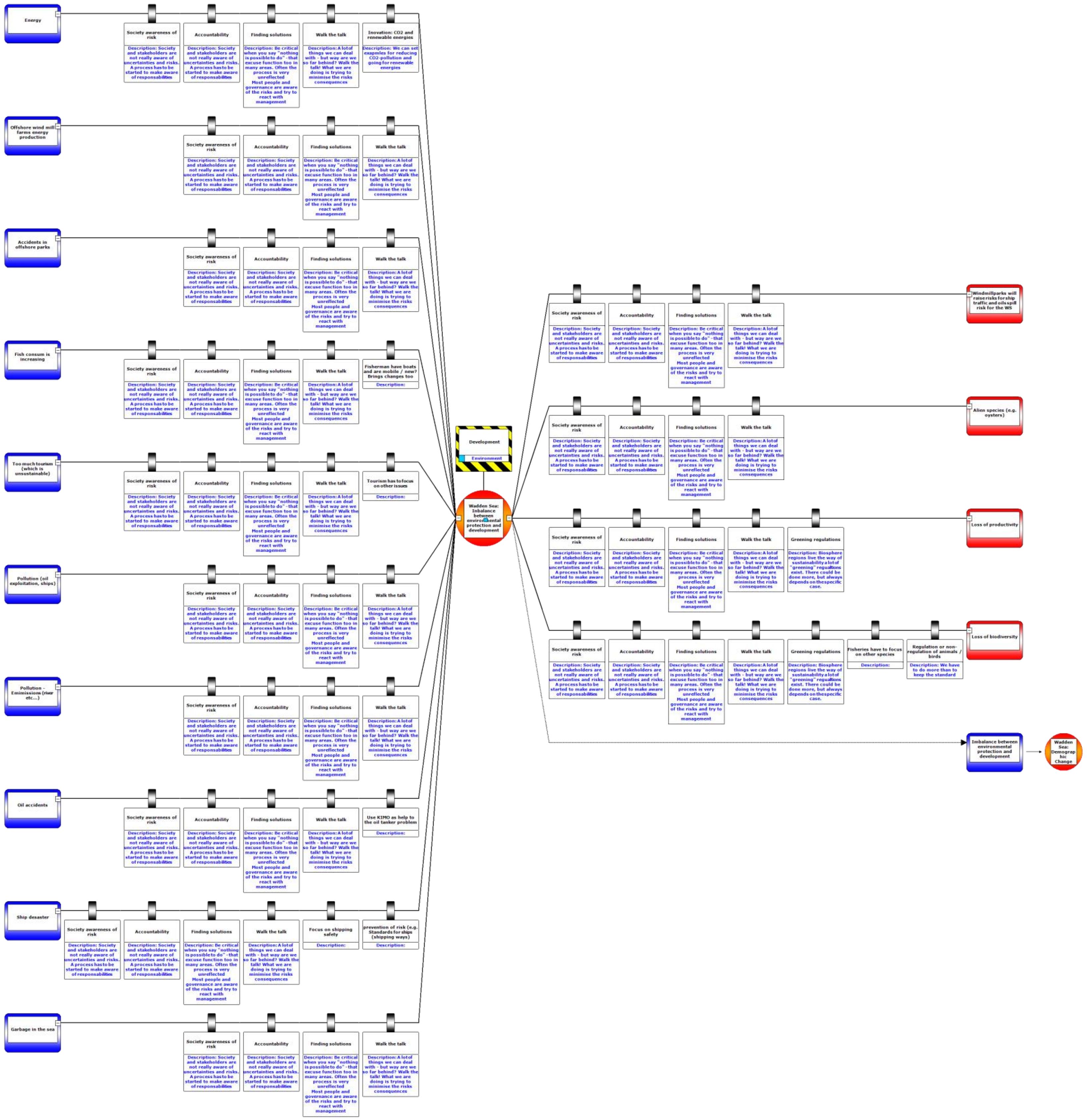
Project name	Subproject / case study	Responsible institution / Person in charge	Year / period	Region	Short description of the project	Methodological approach	Data	Damage estimation
SAFECOAST - Sustainable Coastal Risk Management in 2050		Leadpartner: Ministry of Transport and Waterways, Den Haag;	Juli 2005 - Juni 2008	North and central Jutland; Wadden coast; The Rhine-Meuse-Scheldt delta surrounded; Southeast England and London; East to North East England	SAFECOAST is a follow-up project of the INTERREG IIIB-projects COMRISK, which had been developed based on the advice and the network of the North Sea Coastal Managers Group. It is the main aim of the project to improve coastal protection based on the perspectives of a sustainable and balanced development in the low-lying areas against the background of climate change. Within the project scenarios with regard to mean sea level rise are assessed, social knowledge about flood risks should be improved and risk analysis approaches are compared on a cross-national level. The latter should be foster in order to develop cross-national exchange of knowledge in risk management. Moreover, long-term management plans and research on coastal and erosion risks should be analysed in a pilot study. Synthesis of the project should support future, sustainable coastal protection risk management.	1. Analysis of flood risk assessment + 2. Analysis of coastal erosion assessment: This step is involved with the assessment of • Losses of coastal area and intertidal areas • Impacts of land losses on economic and ecological values. Coastal erosion will generally lead to a direct loss of coastal area and intertidal areas. The extent of these area losses is quantified, from a detailed description of the coastal bathymetry within the coastal sediment cells, and the information on sediment deficits, coastal erosion/accretion and changes in water level. Depending on land use and ecological characteristics of the specific areas potentially lost, an assessment can be made of the loss of economic and ecological values associated with the area losses. An overview of the steps involved with coastal erosion assessment is illustrated in figure 4.5 (Safecoast 2008, p. 59).		The Netherlands: The coastline is 350 km long. Two-thirds of the country (25,000 km2) is at risk of coastal flooding. The flood prone area comprises densely populated polders. The capital value at risk is estimated at 2,000 billion euros (1992). United Kingdom: The coastline is 4500 km long. 2,200 km2 (with 5% of the population), is at risk of coastal flooding: some large urban and agricultural areas, but also very many small areas. The capital value at risk is estimated at 250 billion euros (2000). (Jorissen et al. 2000, p. 9)
	Germany			Schleswig-Holstein	For Schleswig-Holstein, between 1995 and 2000 a meso-scale valuation study of the coastal lowlands was carried out. The main objective of this GIS-based study was the determination of the consequences of a possible flooding of coastal lowlands, especially the assessment of the possible damages and depreciation in value. On the basis of this study it will be possible to conduct benefit-cost analyses for coastal defence works (Jorissen et al. 2000, Appendix 4, p. 4).	For Germany, Klaus & Schmidtke (1990) delivered a meso-scale expert opinion (cost-benefit analysis) for coastal defence works in the "Weserinarsch-area", Lower Saxony. This pilot study functioned as a methodological guide for a coastal defence valuation study that was conducted in the German Federal State of Mecklenburg-Vorpommem. For reasons of comparison, the same expert opinion was used in Schleswig-Holstein. Being a meso-scale study, the valuation is based on aggregated data sets. With a GIS, the following data from different sources were compiled and processed to create a homogeneous database: • physical geographical data − elevation information from a DTM topographical structures from maps, scale 1:50,000 (roads, settlements etc.) − land-use data (Landsat-TM images) • socio-economic data (municipal and district statistics) − inhabitants − houses − roads/infrastructure − motor vehicles − livestock − quality of agricultural soils − touristic capacity (number of beds) − places of work and employees for 10 different sectors of economy − gross increment value and tax yield (running economic results) (FloodingRiskGermany, S.5). The integration of these data with statistical key values results in the entirety of all protected values per municipality. For instance, the multiplication of the number of inhabitants by the average housing capital per inhabitant (key value) results in the housing capital per municipality. In a next step, the study area was divided into so called flood units (Figure 4). Each flood unit represents the area that becomes flooded when a single dike is breached during a storm surge. Each unit is separated from other flood units by other dikes or higher grounds. Normally, the flood units do not fit with the municipalities. However, for coastal defence planning purposes it is important to know what potential damages exist in each flood unit. Hence, the values per municipality were broken down to these units. For this, the method used in the "Weserinarsch-study" was modified to local circumstances. Assuming that economic values and inhabitants are primarily located in the residential sites, the proportion (%) of residential sites per municipality within each flood unit was established. Similar the proportion (%) of agricultural area or rather agricultural values per municipality for each flood unit was determined. With the established percentages the total values per flood unit could than be calculated. Furthermore, with the DTM the values for different height intervals within each flood unit could be appraised. These calculations could be performed by applying the concept of REGIONS, which is implemented in the used GIS software (FloodingRiskGermany, S.6)	Compare Methodical approach	The valuation study delivered the following results for the North Sea coast of Schleswig-Holstein. Along the west coast, an area of about 2,400 km2 is situated less than 5 m above German Ordnance Level and could become flooded during extreme storm surges. In these coastal lowlands, about 250,000 people live, and 31.5 billion euros of economic values are concentrated. Further, 85,000 people work here, producing a yearly gross added value of 4.4 billion euros. The use of GIS for the valuation study turned out to be very time consuming. Almost 90% of total project time was used to compile and process the raw data into a homogeneous database. However, once this database had been established, the powerful analysis-functionality of GIS allowed for an accurate, high-resolution calculation of total protected values per flood unit and height interval (Jorissen et al. 2000, Appendix 4).

Project name	Subproject / case study	Responsible institution / Person in charge	Year / period	Region	Short description of the project	Methodological approach	Data	Damage estimation
XtremRisK - Extreme storm surges at open coasts and estuarine areas: Risk assessment and mitigation under climate change aspects		Verbundsprojekt von:Leichtweiß-Institut für Wasserbau, TU Braunschweig; Institut für Wasserbau, Technische Universität Hamburg-Harburg; Forschungsinstitut Wasser und Umwelt Universität Siegen; Landesbetrieb Straßen, Brücken und Gewässer Geschäftsbereich "Gewässer und Hochwasserschutz" Hamburg	2008 bis 2012		The Project XtremRisK – Extreme Storm Surges at Open Coasts and Estuarine Areas, Risk Assessment and Mitigation under Climate Change Aspects, funded by the German Federal Government, will help facing this challenge. The „Source-Pathway-Receptor"-Concept will be used as a basis for risk analysis and development of new risk management strategies.	The reseracj is based on the „Risk Source-Pathway-Receptor"-concept (Oumeraci et al. 2012, p.12).The approach include an integrative risk analysis seperated in 4 subprojects including the source of risks (subproject 1), the pathway of risks (subproject 2), the risk recipient (subproject 3) and the integration (subproject 4) (Oumeraci et al. 2012, p.12).		
	Subproject 3 - estimation of damages and ist evaluation			Hamburg (Wilhelmsburg); Sylt (Hörnum)	It is the aim of subproject 3 to quantify the extend of damages in the pilot study areas of Hamburg and Sylt resultant from extreme storm surge scenarios. It is th aim to assess the vulnerability exemplarily for a densely populated area behind the dike and for sparsely populated areas on the nordfriesian islands. Using a high water risk model the included damage estimation should be tested and improved by the Xtrem RisK project. It is of main importance that physically based approaches should be applied, which offers the possibility to model single damage processes in order to develop more precise information about the damages. The analysis conducted in subproject 3 includes direct as well as indirect damages.	Based on the „Risk Source-Pathway-Receptor-concept"it is the aim to analyse the tangible damages in the cases study regions. To achieve this aim the subproject 3 uses a deepth-avaraged, 2 dimensional numeric flow model for the research areas, based on the existing model Kalypso (technical university Hamburg Harburg). In a second step, a 2d, hydrodynamic model is used to calculate the input parameters for each case study region (input was given by subproject 2 due to initial conditions for spatial flood extend and the water depth). Based on the steps of the vulnerability analysis in a third step the damage potentials for each damage category were interlinked with each other and the tangible damages were calculated. The results are submitted to the subproject 4 where these data are used for an an assessment of risk for different storm surge scenarios (Oumeraci et al. 2012, p.82).	In order to quantify the damages on a micro and meso-scale in the case study areas, vulnerability assessment was conducted in these areas. Different categories of damages (e.g. buildings and houses, buildings used by industry and businesses as well as infrastructures were considered. Different approaches to typify the categories were developed based on damage functions and interviews and household surveys. Different types of categories were developed under consideration of a) the type of building, b) the use of the ground floor level c) the material of the building as well as the cover of the building. Each element was related to one of the prototype buildings. For each of these prototype buildings the potential damage were estimated based on the replacement process and costs, damage functions were established in steps of 10 cm water level. In addition available data of the economic used were integrated to estimate the damage as good as possible. For infrastructure elements a similar development of prototypes had been conducted (see Oumeraci et al. 2012, p. 85)	The intersection of flooded areas and risk elements for Hamburg Wilhelmsburg results in an estimation of damages at a range of 0 to 325.000 €. Detailed estimated of damages for each category and each scenario could be found in Oumeraci et al. 2012) Direct damages in Mio € for pilot study Wilhelmsburg Scenario HH_XR2010A: residential buildings inventory 67, 57 buildings 572,48; industry and businesses inventory 312,84 buildings 87,15; infrastructure 3,71; agriculture 0,21; total 1.043,96; for scenario HH_XR2010B: residential buildings inventory 0,03 buildings 0,26; industry and businesses inventory 1,00 buildings 2,12; infrastructure 0,01; agriculture 0,02; total 3,44; Scenario HH_XR2010C: residential buildings inventory 223,47 buildings 2.297,04; industry and businesses inventory 1.907,47 buildings 824,53; Infrastructure 242,56; agriculture 0,25; total 5.495,32 (Oumeraci et al. 2013:97). Indirect damages in Mio €: Scenario HH_XR2010A: 25,18 Scenario HH_XR2010B: 0,22 Scenario HH_XR2010C: 87,5 (Oumeraci et al. 2012, p.99). Results for Hamburg-Wilhelmsburg scenario HH_XR2010A: tangible damage (in Mio €) 1.043,96; Risk(€/a) 8.051; scenario HH_XR2010B: tangible damages (in Mio €) 3,44; risk (€/a) 0,2; scenario HH_XR2010C: tangible damages (in Mio €) 5.495,32; Risk (€/a) 291 (Oumeraci et al. 2012, p.112). Results for risk analysis for Hörnum (Sylt): scenario HO_XR2010A tangible damages (in Mio €) 72,99; risk (€/a) 392; scenario HO_XR2010B tangible damages (in Mio €) 13,75; risk (€/a) 975; scenario HO_XR2010C tangible damages (in Mio €) 57,72; risk (€/a) 17.662 (Oumeraci et al. 2012, p.113).

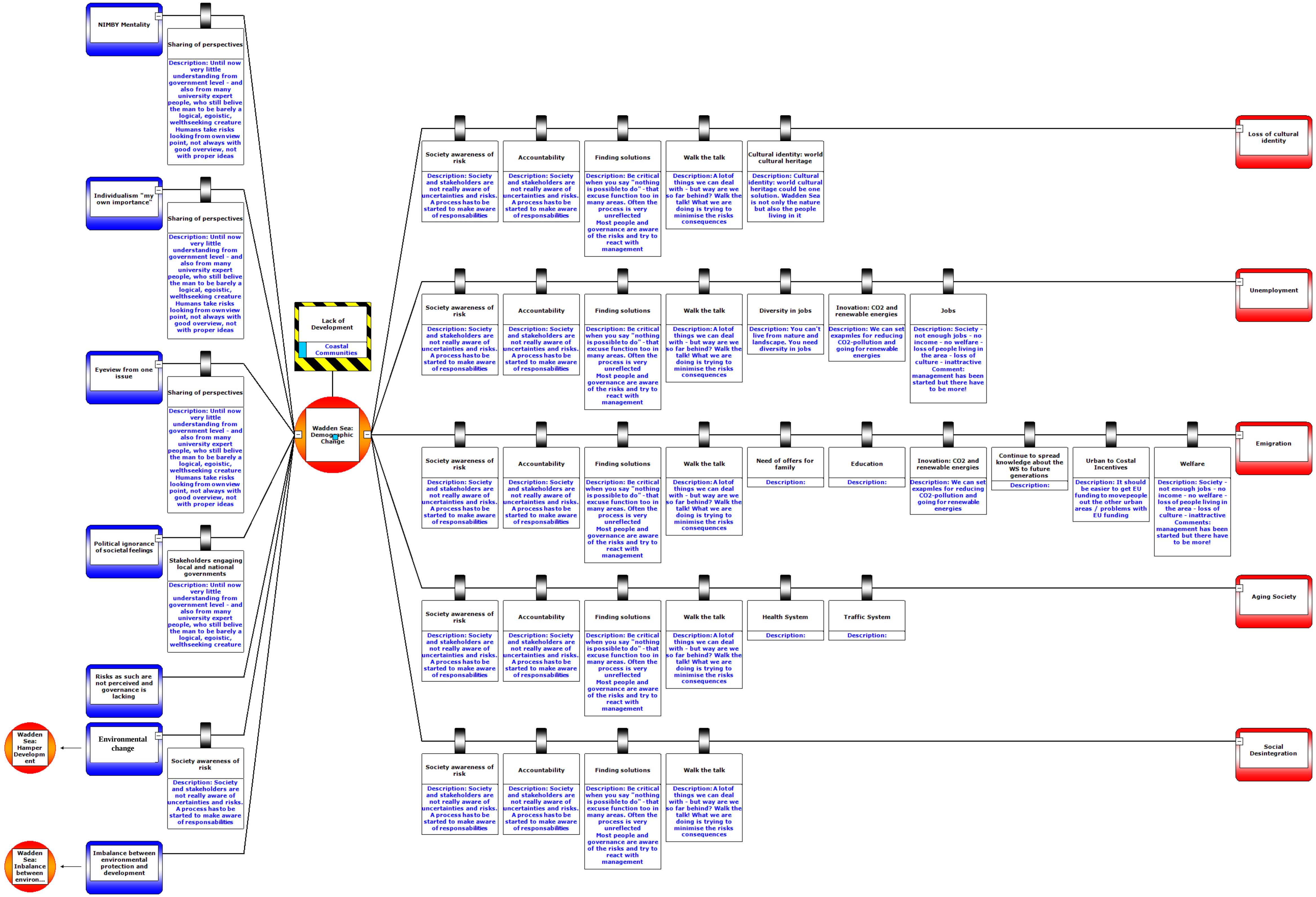
ANNEX B – Results of the Bow-tie analysis about risks in the Wadden Sea Region



Appendix B Figure 1 Detailed bow-tie diagram concerning the threat of environmental changes affecting the coastal communities in the WSR



Appendix B Figure 2 Detailed bow-tie diagram evolving around the worries about an imbalanced development between social, economic and environmental interests



Appendix B Figure 3 Detailed bow-tie diagram dealing with the stakeholders concerns about demographic changes in the WSR