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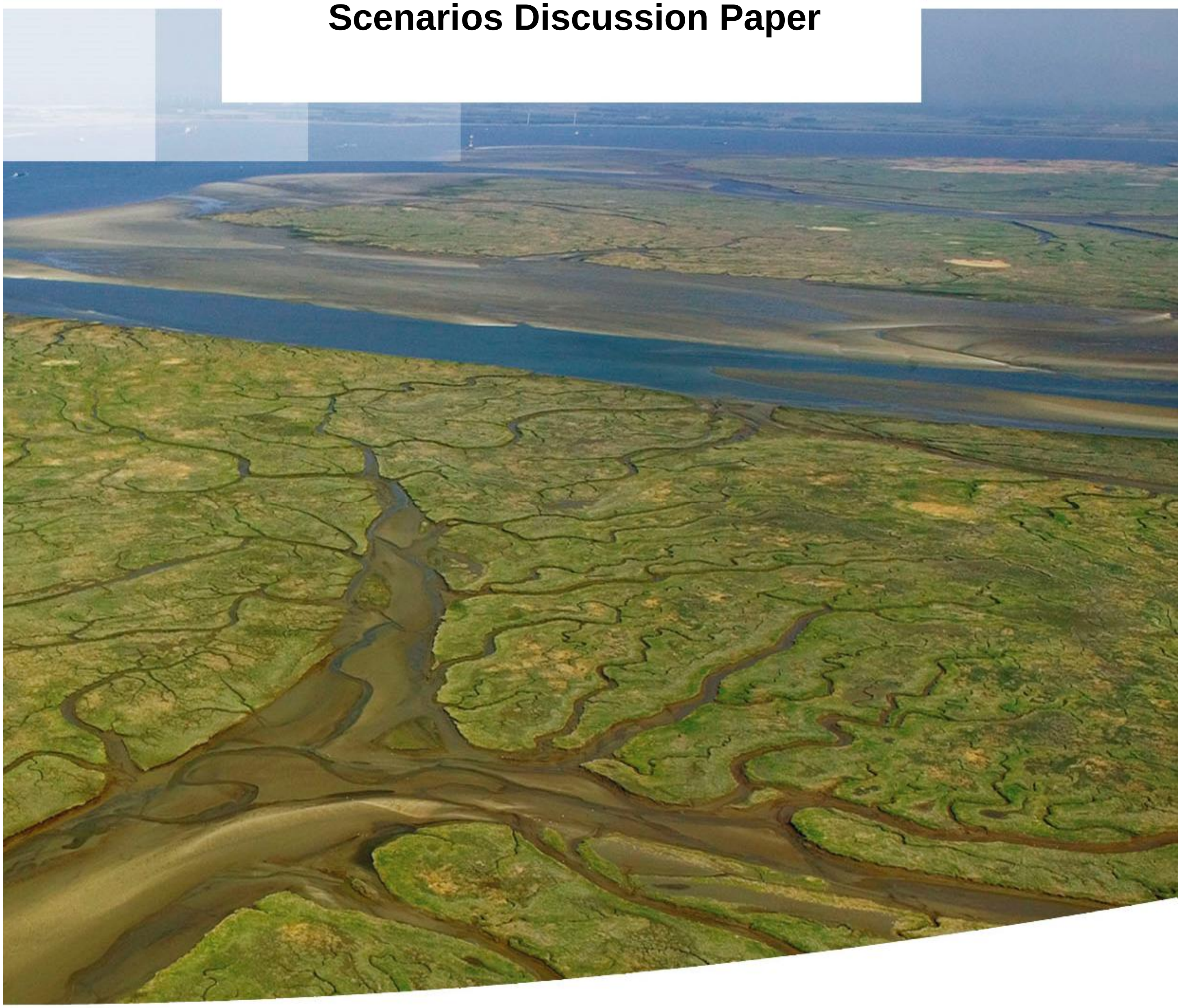
EU Floods Directive in Denmark - Climate Change Scenarios Discussion Paper



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EU Floods Directive in Denmark - Climate Change Scenarios Discussion Paper

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Summary
The Danish Coastal Authority (DCA) is preparing for the second cycle of the implementation of the EU Floods Directive. Within this framework, the DCA aims to also determine the effect of climate change on the flood risk. This memo discusses climate change scenario's, that include sea-level rise and changes in storminess. An overview is provided of best practices in neighbouring countries on including climate change in coastal risk management and urban development plans. Finally, advice is provided on the choice of middle, high, and upper-end scenarios, as well as on levels of acceptable risk and flood protection norms on the basis of economic criteria.

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Contents

1 Introduction

The Danish Coastal Authority (DCA) is preparing for the second cycle of the implementation of the EU Floods Directive. Within this framework, areas with high-risk of flooding will be defined along the Danish coastline. DCA aims at adapting the screening assessment in the second cycle towards a more risk based approach. This will require changes in the screening process to include new knowledge on the physical definition of the size of risk areas, climate scenarios, and the inclusion of both tangible and in-tangible vulnerabilities.

DCA has approached Deltares to support DCA in the transition to a more risk based approach. To target the work on specific issues, three sub-groups have been proposed having participants from both Deltares and the DCA. The topics of the two sub-groups have been defined as follows: (1) Climate change scenarios, (2) Identification of the vulnerability and the risk criteria, and definition of coherent risk management polygons for the appointed flood risk areas. The present report focusses on the first topic, climate change scenarios.

While Implementing the EU Floods Directive in Denmark, the DCA is required to determine the effect of climate change on the flood risk. The effects of climate change have to be incorporated in the risk mapping, on the basis of which the municipalities will develop their risk management plans. The climate change scenarios that will be used for the mapping will therefore be perceived by the municipalities as recommendations on which climate change scenarios for new land and city development plans, new infrastructure, and adaptation plans for current flood protection structures can be based on.

To ensure a better basis for determining which climate scenarios and timeframes to use for risk mapping and risk management, the DCA has requested Deltares to provide an overview of best practices in academia and in other countries on including climate change in development, adaptation and risk management plans.

The present report is set up as follows. Chapter 2 presents the objectives of the project. Chapter 3 provides a review of literature and practice in other countries. Chapter 4 discusses the practical use of climate change predictions for coastal planning. Chapters 5 and 6 provide the conclusions and the recommendations, respectively.

2 Objectives

This report aims at providing:

- Literature review of the latest climate change science;
- Literature review of construction of climate change scenarios from various European countries (The Netherlands, United Kingdom, Germany);
- Literature review of best practice incorporation of climate change scenarios into flood studies and policies from these same countries;
- Discussion on practical use of climate change scenarios for coastal planning;:
- Discussion of a minimising maximum regret approach on the role of climate change and future flood hazard scenarios in coastal planning; and
- Discussion on the selection of the future scenarios to be used and of the associated timeframes.

3 Literature and science review

3.1 Review of climate change science

Not only climate is variable, also the knowledge about climate is rapidly evolving. The Intergovernmental Panel on Climate Change (IPCC) has released the Working Group I contribution to the 5th IPCC Assessment report (AR5; IPCC, 2013), which provides an overview of the state-of-the-art knowledge about observed climate variability and change, its representation in models and future projections.

This section reviews the current understanding of changes relevant to flood risk in coastal areas. It does not aim at reviewing exhaustively the projected changes in climate variables observed in Denmark, as the overall purpose of this report is to provide guidance and recommendations for including projected future climate change into flood risk studies. However, in some cases, these observed changes are relevant for understanding the projected future changes in relevant climatic variables, and therefore these are discussed.

Flooding in coastal areas in Denmark can be affected by high rainfall, high river runoff, or by high sea-levels due to storm surge, or by a combination of these factors. All these factors are potentially affected by climate change and are discussed below.

3.1.1 Mean temperature

The projected global mean temperature increase, derived from the range of values generated by the CMIP5 model ensemble (Taylor et al. 2011), is estimated to be between 0.3 and 4.8°C at the end of the 21st century, in the AR5 IPCC report (IPCC, 2013). The observed temperature increase in Western Europe (including Denmark) during the last 50 years is about twice the increase in the global mean (see also Van Oldenborgh et al. 2009). In addition, a reduction in the number of cold days and an increase in number of warm days and nights in Western Europe are observed.

3.1.2 Precipitation

According to DMI (2014), mean annual precipitation in Denmark has increased by 20% between 1874 and 2012. In mid-latitude wet regions as Western Europe, mean precipitation will likely increase by the end of this century under especially the RCP8.5 scenario (IPCC, 2013). Analyses with global and regional climate models show the following general changes for precipitation in Denmark in the period 2071-2100 in relation to 1961-1990: (1) an increase of 10-40% in winter precipitation and a reduction in the order of 10-25% in summer precipitation; (2) a clear tendency towards more episodes with very heavy precipitation, particularly in autumn and lengthy dry periods, especially in the summer (DMI, 2014).

3.1.3 River discharge

Climate change is projected to affect the hydrology of river basins (AR5 WG2, IPCC, 2014). The discharge that has a current return period of 100 years is projected to increase in Continental Europe, but decrease in some parts of Northern and Southern Europe by 2100 (Rojas et al., 2012). Studies for individual catchments including Denmark indicate increases in extreme discharges, to varying degrees (Thodsen, 2007).

3.1.4 Sea-level rise

The sea level projections in the Summary for Policy Makers of the AR5 report display a range that is larger than in the 4th report. Explicit regional effects, such as changes in gravitational pull by ice cap mass changes, are also included in the assessment. In this respect the effects of Greenland are important for Denmark. For the end of the 21st century (2081-2100), the global sea level is likely to be 26 to 82 cm higher than in the reference period (1986-2005). In Denmark, depending on the RCP scenario that is considered, the sea level rise is likely to be about 25 cm to 30 cm (+/- 20 cm) and 40 to 63 cm (+/- 50 cm), respectively in 2050 and 2100, as estimated by DMI (2014) based on IPCC AR5 report.

3.1.5 Storm surge

There are large uncertainties regarding changes in wind characteristics for Denmark. Still, the wind speed of the more intense storms is expected to increase (DMI, 2014). A storm with return period of 50 years is expected to increase in maximum wind speed by more than 10% in 2050 and even more by 2100. One the other hand, the number of storms is not expected to increase.

3.2 Review of climate change scenarios development in European countries

This section provides a brief summary on how climate change scenarios are developed in European countries (The Netherlands, United Kingdom, and Germany). The guidance provided by each government body relates to their geographical jurisdiction and is not necessarily applicable elsewhere i.e. in Denmark. The review of climate change scenarios is however useful in identifying the physical parameters that have been amended and the mechanism by which hydrologic and/or hydraulic models have been changed to take account of climate change projections.

3.2.1 European level

As pointed out in KNMI (2014), most countries in Europe produce climate change scenarios for their own country, often using the same climate projection information (global climate model – GCM, and regional climate model – RCM projections) from large European projects such as PRUDENCE and ENSEMBLES, but all with their own methods to construct the scenarios, which does not allow for a straightforward comparison. Table 3.1 presents regional climate scenarios of various European countries.

Table 3.1 Regional climate scenarios/projections and their names in various European countries: links to the websites (source: a.o. Dalelane, 2014; links last checked March 30, 2014).

Country	Website with regional climate scenarios
Austria	klimawandelanpassung.at/ms/klimawandelanpassung/de/klimawandelinoe/kwa_zukunftsszenarien/
Belgium	CCI-HYDR for Flanders: www.kuleuven.be/hydr/CCI-HYDR.htm
Denmark	en.klimatilpasning.dk/knowledge/climate/denmarksfutureclimate.aspx www.dmi.dk/klima/fremtidens-klima/klimascenarier/ www.dmi.dk/klima/fremtidens-klima/danmark/ www.dmi.dk/fileadmin/Rapporter/DKC/dkc12-04.pdf
France	DRIAS: www.gip-ecofor.org/gicc, www.drias-climat.fr/ www.meteofrance.fr/climat-passe-et-futur/changement-climatique/projections-climatiques/les-projections-climatiques-regionalisees

Finland	ilmasto-opas.fi/en/ilmastonmuutos/suomen-muuttuva-ilmasto/-/artikkeli/74b167fc-384b-44ae-84aa-c585ec218b41/ennustettu-ilmastonmuutos-suomessa.html; ilmasto-opas.fi/en/datat/mennyt-ja-tuleva-ilmasto#DoubleMapTimelinePlace:vertailu
Germany	DWD Klimaatlas: www.dwd.de/klimaatlas/ KLIWAS: www.kliwas.de/ WettReg2010: www.cec-potsdam.de/Produkte/Klima/WettReg/wettreg.html CSC: www.climate-service-center.de/031443/index_0031443.html.de
Ireland	www.epa.ie/pubs/reports/research/climate/ STRIVE_48_Fealy_ClimateModelling_web.pdf
Netherlands	KNMI’06 and KNMI’14: www.knmi.nl/climatescenarios/
Norway	met.no/Forskning/Klimaforskning/Klimascenarier/ www.senorge.no/index.html?p=klima
Portugal	www.ipma.pt/pt/oclima/servicos.clima/index.jsp?page=cenarios21.clima.xml siam.fc.ul.pt/
Spain	www.aemet.es/es/elclima/cambio_climat/escenarios
Sweden	www.smhi.se/klimatdata/Framtidens-klimat/Klimatscenarier/2.2252/2.2264 www.mistra-swecia.se/
Switzerland	CH2011: www.ch2011.ch/
UK	UKCP09: ukclimateprojections.defra.gov.uk/

Table 3.2 just focusses only on The Netherlands, United Kingdom and Germany as they will be discussed in more detail in the following sections. Table 3.2 shows that three countries use different emission scenarios as well as different global and regional climate models. Therefore, the projections for the future will be different for each country.

Table 3.2 Regional climate scenarios/projections in various European countries: some characteristics (source: Dalelane, 2014).

Country	Scenarios	Reference	Time	Ensemble	Source	Differentiation
Germany	9 emission scenarios (RCMs)	1961-1990	2000-2100	Multi-model, A1B	ENSEMBLES	25*25 km and river basins
Netherlands	4 emission scenarios	1981-2010	2030, 2050, 2085	Multi-model, multi-emissions	CMIP5 + ensemble of EC-EARTH and RACMO	Only for temperature
U.K.	3 emission scenarios (B1, A1B and A1FI)	1961-1990	2020s 2050s 2080s	Perturbed physics ensemble, multi-emissions, one model	Model Hadley Centre	25*25 km, administrative regions, river basins

Figure 3.1 gives an example of the differences in ranges for future temperature and precipitation changes that are spanned by some of the climate scenario sets available from countries listed in Table 3.1. The ranges are rather difficult to compare, since the reference periods and time horizons also differ between countries (Dalelane, 2014).

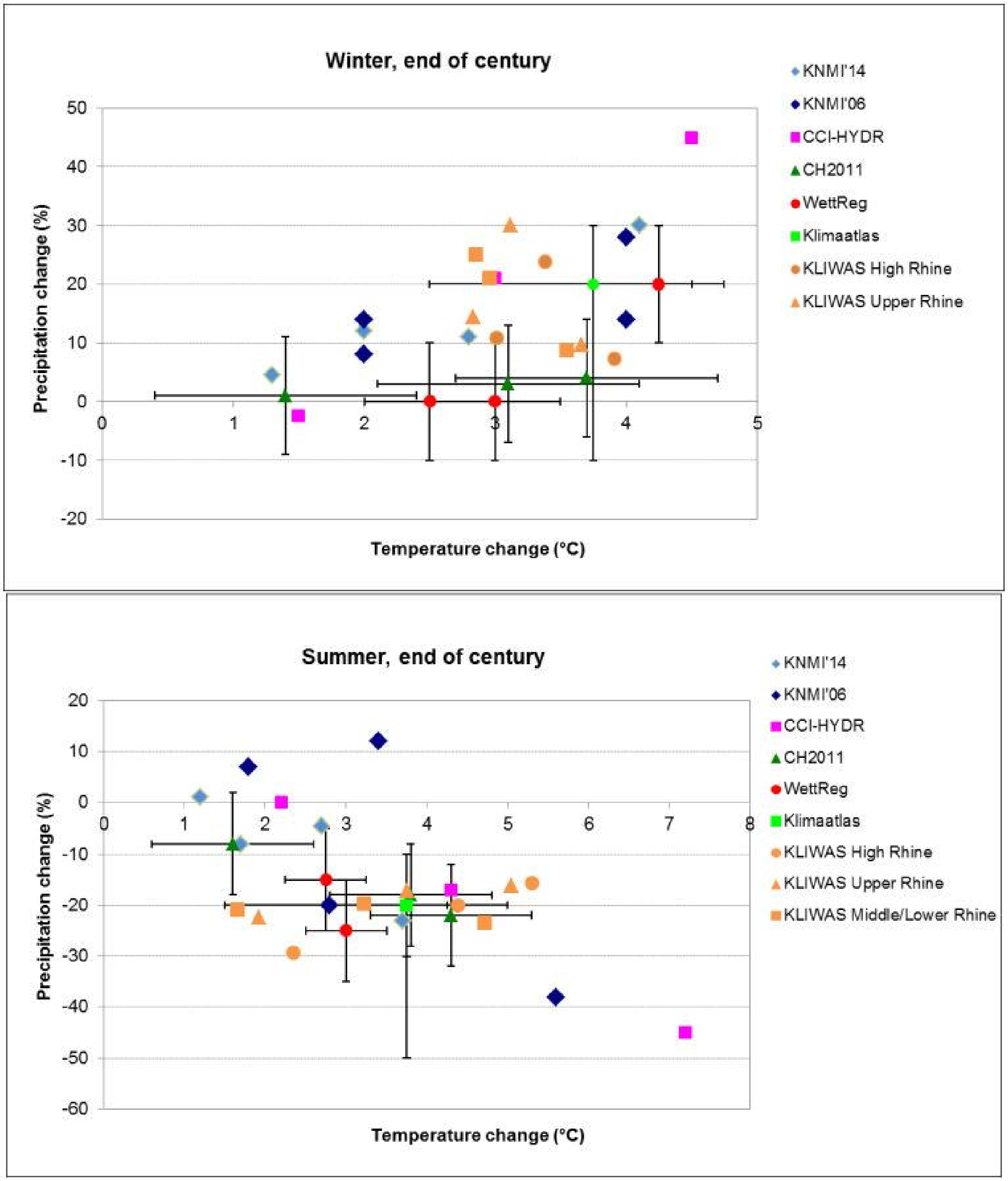

Figure 3.1 Graphical comparison of various sets of regional climate change scenarios in Europe: changes in average temperature and average precipitation in winter (upper panel) and summer (lower panel) for the end of the 21st century. Source: Dalelane (2014).

3.2.2 The Netherlands

In the Netherlands, the KNMI (Dutch meteorological office) has developed four future climate scenarios. Two scenarios are representing global temperature increases of +2 degrees (moderate), and two scenarios are representing increase of +4 degrees (warm) by 2100. Both the moderate and the warm scenarios have two associated air circulation scenarios . Each scenario has its own suite of projected climatic parameters set for future timelines.

When first developed in 2006, all four scenarios were considered equally likely to occur (van den Hurk et al., 2006). However, in 2010, it was officially released that based on measured rising temperature the warmer scenarios were more likely to occur (Klein Tank and Lenderink, 2009).

To take this into account in practice, a Governance Agreement on Water was signed in 2011 (http://english.uvw.nl/), which describes the scenarios that should be used to get insight in the relevant climate impacts on water in 2050/2100. In practice often two or more scenarios are taken as input for hydrological models, so it results in a range of outcomes.

For many engineering issues, the scenario values need to be associated with representative information about possible future weather conditions. As part of the KNMI'06 scenarios, software has been developed which transforms observed daily records of temperature and precipitation into time series representative for the future climate, i.e. a statistical transformation of historical records that brings the seasonal averages and (moderate) extremes in agreement with the scenarios. See http://climexp.knmi.nl.

In 2014, KNMI released a new set of scenarios, the so-called KNMI'14 climate scenarios (KNMI, 2014). More info can be found on the website of KNMI, following the link http://www.climatescenarios.nl/. The four KNMI'14 scenarios differ in the extent to which the global temperature increases ("Moderate" and "Warm", so-called G and W scenarios), and in the possible change of the air circulation pattern ("Low value" and "High Value", so-called G_L and G_H scenarios for the "Moderate" scenario), see Figure 3.2 below.

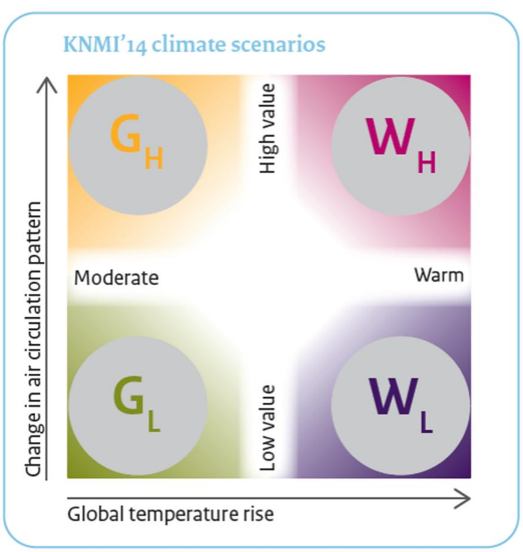

Figure 3.2 The KNMI 2014 scenarios.

In many aspects, the new climate change scenarios are different from the previous generation (KNMI’06). They now give the change around 2030 (2016-2045), 2050 (2036-2065) and 2085 (2071-2100, the maximum possible time horizon because most GCM calculations run up to 2100) compared to the climate in the period 1981-2010, whereas the KNMI’06 were using the period 1976–2005 as reference. As pointed out by KNMI (2014), The KNMI'14 climate scenarios show a picture of higher temperatures, accelerating sea level rise, more wet winters, more intense showers and higher chances of drier summers. The scenarios also include new and more detailed information. For example, they give snapshots of future weather and provide information about fog, radiation, evaporation and hail. The scenarios provide up to 40 cm sea level rise in 2050, 80 cm in 2085 and 100 cm in 2100.

While constructing climate scenarios, the important question to answer is: what are the criteria that need to be satisfied to consider climate scenarios to be useful? (KNMI, 2014) Since the KNMI’06 project, the criteria for useful climate scenarios were plausibility, internal consistence and relevance. Plausibility implies that the scenarios have some realism and probability that they occur in the real world. Internal consistence implies that the different atmospheric variables within each scenario are physically consistent and well understood, and are supported by quantitative evidence obtained from models and observations. Relevance (or salience) is ensured by generating climate change variables that are considered useful by a large group of users.

3.2.3 United Kingdom

The Environment Agency is the primary body responsible for flood risk management in England and Wales. The Agency provides detailed and comprehensive advice on how to incorporate climate change projections into flood risk management projects, following the UK Climate Impact Programme 2009 (UKCIP09). The full report is “UK Climate Projections science report: Climate change projections” from the Department of Environment Food and Rural Affairs (DEFRA, 2009). The advice is summarised in another report “Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management Authorities” (UK Environment Agency, 2011).

As indicated by Smyth et al. (2014) who carried out the review of a.o. the UK practice in accounting for climate change in flood modelling, the advice by the UK Environment Agency is provided on factors (either mm or %) to be incorporated for rainfall, river flow, sea level rise, storm surge and wave climate to take account of the potential impacts of climate change. Upper and lower end factors are also provided to allow for analysis of scenarios either side of the median climate change scenario.

The climate change projections based upon a 2˚C and 4˚C change in Global Mean Temperature (GMT) by the 2080s from the 1990s baseline form the lower end and mean scenarios, respectively. A more severe H++ scenario is considered as an upper end scenario.

For the scenario based on a 2° change in Global Mean Temperature, the low emissions 50%ile as published by UKCP09 is used to estimate the relative sea-level rise. The average values within each coastal region are taken directly from the UKCP09 data without modification. These values are equivalent to the lower end estimate from UK Environment Agency (2011). UKCP09 is known to exclude a number of processes important to sea level rise, and some adjustments have been made to take into account higher estimates of changes including sea-level rise, see Sayers et al. (2014) for more details.

For construction of the severe H++ scenario (Wade et al. 2015), a 70%-100% increase in winter (Dec to Feb) rainfall, from a 1961-1990 baseline, is considered as well as an up to five-fold increase in frequency and 60% to 80% increase in heavy daily and sub-daily (e.g. hourly or 2-hourly) rainfall depths, for both summer and winter events (all year round). With respect to high river flows, a 60% to 120% increase in peak flows are considered at the 'lower end' of the H++ scenarios for some regions in England and Wales. The upper limit for any region is a 290% increase in peak flows (1961-1990 baseline). The scenarios are based on the average response of "Enhanced-high" catchments, which are particularly sensitive to increases in rainfall. Finally, a 50-80% increase is considered in the number of days per year with strong winds over the UK (1975-2005 baseline). A strong wind day is defined as one where the daily mean wind speed at 850 hPa, averaged over the UK (8W-2E, 50N-60N), is greater than the 99th percentile of the historical simulations.

Moreover, depending on the confidence in the underpinning climate science, the advice given for each physical variable (rainfall, river flow, etc.) is further refined for UK sub-regions and different future timeframes. For the purpose of illustration, an example of this advice is given in Table 3.3. The Table shows, for example, that the recommended increase in river flow in 2080 under the predicted climate change scenario (so-called "change factor") is either 20 or 25% depending on the UK sub-region. Under an "Upper end" climate change scenario this increases to either 50 or 70%.

Table 3.3 Changes to river flood flows by river basin district compared to a 1961-1990 baseline (source : Smyth et al., 2014).

UK region	Total potential change anticipated for the 2020s	Total potential change anticipated for the 2050s	Total potential change anticipated for the 2080s
Northumbria			
Upper end estimate	25%	30%	50%
Change factor	10%	15%	20%
Lower end estimate	0%	0%	5%
Humber			
Upper end estimate	25%	30%	50%
Change factor	10%	15%	20%
Lower end estimate	-5%	0%	5%
Anglian			
Upper end estimate	30%	40%	70%
Change factor	10%	15%	25%
Lower end estimate	-15%	-10%	-5%
Thames			
Upper end estimate	30%	40%	70%
Change factor	10%	15%	25%
Lower end estimate	-15%	-10%	-5%

In Scotland, the Scottish Environment Protection Agency (SEPA) is the regulatory body responsible for managing flood risk and has a statutory consultation role in assessing development applications. SEPA provides Technical Guidance on preparing a flood risk assessment, via their document “Technical Flood Risk Guidance for Stakeholders” (2013). The guidance states that: “best estimates, based on the most up-to date findings, should be made of climate change impacts on probabilities, flood depths and extents for both fluvial and coastal situations” (Smyth et al., 2014). For fluvial design discharge estimation, SEPA recommends that a climate change allowance of +20% on the estimated 200 year peak flow should be made. For projected increases in sea level rise, SEPA refers to UKCIP09.

Tang and Dessai (2012) evaluated the usability of the UK Climate Impacts Program (UKCP09; McKenzie-Hedger et al. 2006) scenarios using a mixed set of methodologies involving both constructors and users of the scenarios. Their selection of criteria reflects the level of usefulness as experienced by the user: credibility, salience and legitimacy were explored. Credibility points at scientific soundness, which excludes scenarios that are either very unlikely or physically implausible. Salience implies that the scenarios are fulfilling the user’s needs and are consistent with their frame of reference. Legitimacy expresses the degree to which the scenarios where constructed in a transparent way and consider different views and values (Cash et al. 2003).

3.2.4 Germany

The marine and coastal climate change research is considerably supported at federal level in Germany. As indicated by Policy Research Corporation (2009), the German research is conducted in the framework of Germany’s High-Tech Strategy on Climate protection and is mainly carried out by three marine and climate Clusters of Excellence in Bremen, Hamburg and Kiel and in many institutes across the country. Climate modelling and prognoses methodologies differ however amongst the various institutes. Service institutions such as the scientific regional climate bureaus or the Climate Service Centre (CSC) have been established about 10 years ago.

The German Coastal Engineering Research Council (KFKI) initiates studies directed towards the prediction of natural phenomena, aiming at the environmentally friendly and sustainable use of coastal and adjacent areas. Within KFKI, projects are funded that deal with topics such as sea/dike interaction, probabilistic model approaches to flooding of coastal areas, or the high resolution analysis of tidal water levels (Policy Research Corporation, 2009).

In 2006, the Federal Ministry for Environment established under the Federal Environment Agency, KomPass 5, a centre on global warming and adaptation to climate change. KomPass aims at integrating available climate research results, to educate decision-makers of public administrations and businesses as well as the general public on climate change effects, impacts and adaptations needs.

The different German states decide independently on the research results and climate scenarios they take into account in their Coastal Defence Master Plans (see section 3.3.3). Although many effects of climate change are investigated in Germany, Sea Level Rise is the only formal scenario considered in the different Master Plans.

Research results on changes in storm surges or wave run-up are considered too premature for use at this stage. As to the frequency of storm days, initial studies show no changes from current conditions (Government of the Federal Republic of Germany, 2010) or too many uncertainties to permit clear projections (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, 2009). Some researchers, however, conclude that more North Sea storms might be generated leading to increases in storm surges along the North Sea coast, especially in the Netherlands, Germany and Denmark (Woth et al., 2005; Beniston et al., 2007). A review of recent scientific literature shows that the projected changes in wind extremes (speed and direction) for the North Sea region are typically within the range of natural variability and can even have opposite signs (i.e. increase and decrease) for different scenarios either simulated by different climate models or for different future periods (May et al., 2016).

3.3 Review of climate change scenarios incorporation into policy

This section provides a brief summary of existing guidance and policy from selected international government bodies (The Netherlands, United Kingdom, and Germany) on how they incorporate climate change information into flood risk management projects and coastal planning policies.

3.3.1 The Netherlands

The Netherlands are shaped by its adaptation to climate variability. It has a long history in coping with variable water levels, from sea, rivers and lakes. Dutch authorities are aware that climate is not stationary (KNMI, 2014).

The last decade has seen a paradigm shift in the national attitude towards adapting to climate variability. Traditionally, adaptation measures were designed and implemented in response to past climatic events that have had a high society impact, in particular after the dramatic 1953 storm surge disaster. The modern ambition is to shape the Dutch Delta while anticipating possible future conditions (www.deltacommissaris.nl), that may differ systematically from today's conditions due to an anthropogenic effect on climate and socio-economic changes. This implies that for instance the design discharge of the major rivers Rhine and Meuse (discharge volume that is used as reference for the design of flood mitigation measures) should not only be quantified for current climate and socio-economic conditions, but should take foreseeable changes in discharge statistics and land use practices into account (Deltacommissie 2008).

The approach followed in the Dutch Delta Program illustrates this orientation on future conditions, which are governed by a combination of natural and human induced changes. The design and evaluation of measures aiming at a robust Delta infrastructure are guided by the so-called Delta Scenarios (Bruggeman et al. 2013) in which key indicators of both future climate and socio-economic conditions are quantified. These Delta Scenarios are based on a selection (and modification) of the previous set of KNMI climate change KNMI'06 scenarios (KNMI, 2014). Apart from the design of the Dutch delta, future climate conditions also play a role in decisions related to sewage design, city planning, nature conservation, health and others (Deltacommissie 2008).

When referring to flood protection and in order to evaluate whether the flood protection strategy is capable of coping with future climate conditions, an assessment of low-probability/high-impact scenarios has been also conducted, focusing mainly on sea level rise, at request of the Delta Committee. A plausible high-end scenario of 0.55 to 1.15 m global mean sea level rise, and 0.40 to 1.05 m rise on the coast of the Netherlands by 2100 (excluding land subsidence), and more than three times these local values by 2200, has been developed (Katsman et al. 2011).

Not surprisingly, this high-end estimate lies above the IPCC projections, which represent a likely range and incorporate only a limited range of possible ice sheet responses, as they do not include potential contributions resulting from rapid dynamical processes in Greenland Ice Sheet (GIS) and Antarctic Ice Sheet (AIS). The high scenario (KNMI'15 W_H scenario) for local sea level rise aims at forming now the basis for updated flood protection strategies for the Netherlands (Deltacommissie 2008; Kabat et al. 2009).

For concrete planning and design, KNMI however deliberately avoided having a mean, high and low scenario. The rationale behind this is that this does not allow policymakers to pick a middle scenario for planning, but requires them to consider a wider range of choices, and explicitly support their choice for a particular scenario. For policy assessments it makes sense to take the most appropriate scenario, to test the proposed risk reduction measures. For instance, in the case of water supply, the W_H scenario with highest temperatures and thus water demand, as well as highest rainfall reduction in summer was assumed to test water supply measures. In the Delta programme, the full range of scenarios is considered by the national government and local authorities deciding on the planning and implementation of measures. Given that an 'Adaptive Management' approach is chosen in developing the main flood protection strategy, no prescribed scenario for the end of the century (2100) is chosen, and neither are the worst case scenarios used (Deltaprogramme, 2015). However, in the practical design of long-lived infrastructure, a choice has to be made. At present, the guidance for the design of protection infrastructure along the main rivers, including levees and dams and associated works, advises to account for the W_H scenario of KNMI (RWS, 2015).

3.3.2 United Kingdom

Under the 2008 Climate Change Act, the UK Government is required to publish a Climate Change Risk Assessment (CCRA) every five years. The first CCRA assessment was published in 2012 and the second is due in 2017. This assessment will support the development of the next National Adaptation Programme (NAP) for England due in 2018, as well as the national adaptation programmes of Scotland, Wales and Northern Ireland.

The two climate change projections (based upon a 2˚C and 4˚C change in Global Mean Temperature (GMT) by the 2080s from the 1990s baseline; respectively lower end and mean scenarios in Table 3.3), the more severe H++ scenario (upper end in Table 3.3) and three population growth projections (low, high and no growth) are considered together with six Adaptation Scenarios (including assumed enhanced and reduced adaptation levels when compared to present day). Each Adaptation Scenario reflects a range of individual Adaptation Measures to manage the probability of flooding, manage exposure to floods and reduce the vulnerability of those that are exposed. Future flood risks are projected for the 2020s, 2050s and 2080s (Sayers et al., 2014; Smyth et al., 2014).

The UK Future Flood Explorer (FFE) is used to complete the analysis. The UK FFE uses nationally recognized source, pathway and receptor data from across the UK to construct an emulation of the present day flood risk system and to explore the future change in flood risk (taking account of climate change, population growth and adaptation). The flexibility of UK FFE enables multiple futures to be explored and compared, and for the first time, the impact of adaptation, climate change and population drivers to be disaggregated. The National

Adaptation Programme (NAP) will then aim at guiding towards the selection of the most effective Adaptation Measures, as those that act to reduce the probability of flooding.

3.3.3 Germany

At present, no coastal defence, risk reduction or adaptation plans are available at the national level. With the creation of the KomPass competence centre in 2006, the Ministry of Environment announced the development of a national scheme of adaptation to global warming. As to spatial planning regulation, the German states use the 2008 Federal Spatial Planning Act as a legally binding document to establish their own legislative structures and laws (for example: according to the Lower Saxony Dike Law constructions are not allowed in a 50 m buffer zone).

At the sub-national level, every German state has its own Coastal Defence Master Plan, except for Lower Saxony and Bremen who drafted their plan jointly and Hamburg who publishes annual Building Programmes instead. Actions to protect the Wadden Sea eco-systems are coordinated by the Wadden Sea Secretariat, but each country (Denmark, Germany and the Netherlands) bears the responsibility for its respective Wadden Sea coastal area.

Coastal Defence Master Plans
Table 3.4 lists the most recent Master Plans on Coastal Protection in Germany. These Master Plans are not legally binding, but are a strong self-commitment of the state government which adopts the Plan. The reinforcement of dikes to protect against the risk of flooding is the main action undertaken, although authorities are beginning to realise that maintaining and improving hard defences can become rather costly in the long run. Sea Level Rise has been taken into account by each single state government.

Table 3.4 Overview of the German coastal defence plans in relation to climate change (Policy Research Corporation, 2009)

	Schleswig-Holstein Master Plan	**Lower Saxony, Bremen Master Plan**	**Mecklenburg-Vorpommern Master Plan**	**Hamburg Master Plan and Building Programmes**
Responsibility level	State Schleswig-Holstein	State Lower Saxony State Bremen	State Mecklenburg-Vorpommern	City of Hamburg
Planning period	2001-2015	2007-2025	n.a.	1990-2012
Protection level	1:100	n.a.	n.a.	1:400
Scenarios used	SLR: 50 cm / 100 year	SLR: 50 cm / 100 year	SLR: 15-25 cm / 100 year	SLR: 30 cm / 100 year
Protection against	Flooding and erosion	Flooding and erosion	Flooding and erosion	Flooding
Costs	€ 282 million	LS: € 520 million Bremen: € 205 million	€ 128 million	€ 600 million

Note: Costs are solely related to capital measures, implemented by the respective state over the respective planning period and co-financed by the federal government up to 70%.

Coastal protection in the Wadden Sea region
Since 1978, the responsible ministries of the Netherlands, Denmark and Germany have been working together on the protection and conservation of the Wadden Sea covering management, monitoring and research as well as political matters. Trilateral Governmental Conferences held every 3 to 4 years are the highest decision-making body in the framework of the collaboration.

Questions regarding climate change, especially sea-level rise, entered the political agenda of the Wadden Sea cooperation in 1997. An expert group was established to investigate the potential impact of sea-level rise for the Wadden Sea eco-systems and to develop recommendations for coordinated coastal defence and nature protection policies in the Wadden Sea. The results of their work have been detailed in three reports, published in 2001, 2005 and 2010. The reports address the impacts of sea level rise on the Wadden Sea ecosystem (CPSL report 1, 2001), best practices to deal with enhanced sea level rise (CPSL II report, 2005), the relevance of spatial planning for managing the impacts of climate change and the role of sand nourishment for compensating sea level rise (CPSL III report, 2010).

The IPCC scenarios formed the basis for the methodology applied in the evaluation of the possible impacts of sea level rise and changes in storminess to the Wadden Sea ecosystem (CPSL, 2010). As time horizon for the evaluation the year 2050 was chosen. On the basis of the IPCC scenarios, an average sea level rise between 4.5 and 44 cm is expected. In addition to the absolute sea level rise, subsidence of the Wadden-sea floor causes a relative increase of the water level. Therefore a range of 10 to 50 cm was taken as the expected increase until 2050. Within this range, three scenarios were distinguished by the CPSL. In Scenario 1, a sea level rise of 10 cm/50 years is assumed, reflecting the current situation. Scenario 2, the intermediate and most realistic scenario, according to CPSL III report (2010), assumes a sea level rise of 25 cm/50 years and under scenario 3, the worst-case scenario, a sea level rise of 50 cm until 2050 is expected. The possible impact of increase in storminess has been evaluated in addition to the impact of rising water levels.

The main recommendations of the group include:
- Consider coastal defence and climate change in coastal spatial plans and verify the feasibility of such plans with the support of experts from nature protection, spatial planning and coastal defence;
- Apply sand nourishments wherever feasible to combat erosion along sandy coastlines;
- Carry out a feasibility and impact study of sand nourishments to balance the sediment deficit of the Wadden Sea tidal basins under increased sea-level rise;
- Establish regional salt marsh management plans.

3.4 Conclusions

From the review above it becomes clear that the different countries have adopted several approaches for climate change scenario selection and use, to fit their needs. Often a “middle” or “high” climate change scenario is adopted for practical use.

All countries agree that the inclusion of some notion of possible upper-end estimate of changes is important, but these are not always explicitly taken into account or used for planning. In the next section, choices for specific scenarios are discussed in more detail.

4 Practical use of climate change predictions for coastal planning

4.1 Role of climate change and future flood hazard scenarios in coastal planning

Climate change scenarios are plausible representations of the future climate constructed for investigating the potential consequences of human induced climate change. Often a set of climate scenarios is constructed in such a way that they span a considerable part of all possible future climates.

Given the objective of most impact, adaptation and vulnerability studies (i.e. to explore the range of possible impacts and to search for robust adaptation measures), it is useful to use a set of climate scenarios. By comparing the results of the various climate scenarios one can also determine how robust various adaptation measures are. Adaptation measures that work well for most or all scenarios are of interest to policy makers, as they represent measures that lead to no or little regret.

To explore the potential impact of climate change one can also look at potential tipping points, situations or climatic conditions in which the current management or policy is no longer tenable (Kwadijk et al., 2010). In a second stage, one can then determine when these tipping points will be reached under the various climate scenarios.

The results of the impact, adaptation and vulnerability studies often play a role in the formulation of policies and strategies. In this phase often a choice for one or more climate scenarios is made as the basis for policies, although this is not always the case. The choice for one or several climate scenarios is determined by, amongst others:

- What is accepted by society e.g. because of the investment costs now and in the future, or requirements for behavioural change?
- What are the possible impacts/risks of climate change?
- What are the possibilities and costs to adjust a “wrong choice” with later policies?
- What are the costs incurred in case climate change is less than previously assumed, or what are the costs of additional investments in case climate change is worse than previously assumed?
- How fast can further adaptation measures be implemented (e.g. raising of sea dikes takes more time and money than supplying extra sand to the beach to protect the coast)?
- Which scenarios are perceived to be more likely (e.g. if one assumes that greenhouse gas emissions will remain high, then a strong increase in temperature can also be considered more likely)? Note that for instance IPCC does not indicate which of their scenarios is more likely than the others.
- Which climate scenarios are most relevant (e.g. industries that use surface water as cooling water, are likely to be more interested in the scenarios with strong increases in (summer) temperatures, and consequently at greater risk of a shortage of cooling water)?

For policy decision-making, in most cases it is better to ask which climate scenario is most relevant for the user, and not which one is most probable. For instance, in cities, flooding mainly occurs after heavy showers (in North-western Europe especially in summer). In that case, the climate scenario with the largest increase in extreme summer showers is probably most relevant to study potential future risks.

This chapter will investigate the role of climate change and future flood hazard scenarios in coastal planning. More especially, their timeframe, worst case versus more moderate scenarios, and their role in awareness-raising and of influence on long-term coastal developments will be discussed.

4.2 Which scenario's and timeframe to use

Given the high uncertainties associated with sea-level rise scenarios, flexible approaches are now increasingly proposed and implemented. This means that because the future is inherently unknown, decisions to invest in flood protection are made carefully, so that overinvestments are avoided. For instance, flood protection measures implemented in the short term leave the option open to increase and improve the protection at a later stage, if needed. This is often called an adaptive planning approach. And this is an alternative to planning for upper-end estimates of sea-level rise. Table 4.1 indicates the terminology used in this chapter to indicate sea-level rise scenarios.

Table 4.1 Terminology used to indicate sea-level rise scenarios

Scenario name	Typical sea-level rise scenario's
Low	IPCC AR5 likely range
Middle	
High	
Upper-end	Katsman et al., 2011; De Conto and Pollard, 2016

Hinkel et al. (2015) indicate that the IPCC range of sea-level rise scenarios from the Fifth Assessment Report (2013) is not so useful for the practice of coastal protection, because the high-end scenarios are what will determine the actual flood risk in the future. But these are highly uncertain due to the currently limited understanding of long-term ice-sheet dynamics. Recently, there are suggestions that ice sheet loss in e.g. Antarctica may be higher than previously thought (see De Conto and Pollard, 2016). IPCC is planning to bring out a new report on ice-sheet dynamics and oceanic response in the course of 2018. Therefore Hinkel et al. (2015) propose a three step approach:

1) Invest in measures that keep an area safe in the near term (say to 2050) and keep longer-term options open
2) Monitor sea-level rise over time; and based on this:
3) Update the assessment of the longer-term upper bound and implement new measures as appropriate.

This leads to the differentiated use of scenarios for the medium (2050) and long term (2100) timeframes. Also, middle and high or even upper-end scenarios can have a role to play in this approach. For instance coastal policy in The Netherlands has proposed already in 2000 to use middle scenario (60 cm per century) for long-term investments (order of 50-100 years), and use a high scenario (85 cm per century, and +10% increase in storm wind speed) for reservation of space behind narrow dikes and dunes (RIKZ, 2000 p. 36). This use of a high scenario for coastal protection already dates from 1995, where it was decided to reserve space behind coastal defences and dunes for coastal protection with a 200 year time horizon.

The Delta Committee (2008) proposed for 2050 to use the KNMI 2006 scenarios (0.2-.04 m) for implementing flood protection measures, but also to have an adaptive policy. This adaptive policy would include the monitoring of knowledge development on sea-level rise; taking into account possibility of high-end sea-level rise estimates given current high emission pathways and possible ice-sheet responses.

4.3 Awareness-raising and influence on long-term coastal developments

For awareness-raising in local communities, spatial reservations behind coastal defences are important, for keeping flexibility and possibility to increase and strengthen coastal defences. For this purpose, a high scenario can be useful as this determines the maximum space possibly required.

Coastal development and coastal protection works are closely linked. Urban expansion will increase the need for reduced flood probabilities, and for improved protection. Improved protection often spurs economic and urban development (the levee effect).

Combinations of climate and socio-economic scenarios can help to illustrate the interplay between flood probabilities and risks associated with urban expansion on the coast.

4.4 Flood protection levels

Climate scenarios have often been used to inform decisions on coastal protection (see also Chapter 3.2), as well as coastal urban development. For coastal protection information is needed on future hydraulic conditions for the upgrading (heightening and/or strengthening) in the near future (e.g. 2050) of coastal dikes, harbours and dams; as well as possible needs for further upgrading in the more distant future. Scenarios can also aid the assessment of future flood hazard for coastal communities that are planning further coastal urban development, and current and future requirements for flood protection.

At the same time, the level of protection that is required for a given coastal population may be equally important to consider in coastal planning. Based on economic theory, an optimum is sought between costs and benefits (reduced flood risk costs), so as to minimise total costs (see Figure 4.1).

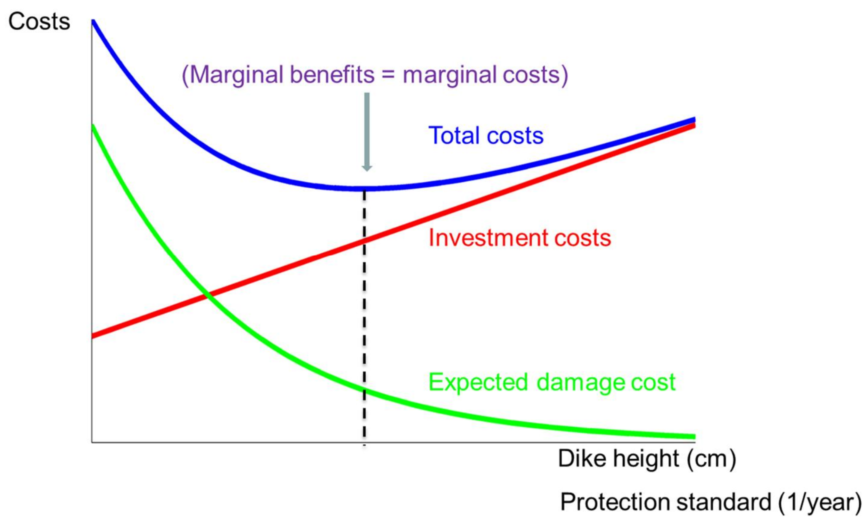

Figure 4.1 Costs associated to protection level

The Netherlands Delta decision on flood safety (2015) has established a flood protection norm (standard), which has been accepted by parliament in summer 2016 and has been set in law. This standard has been determined as flood probability for different coastal (and river/inter tidal) segments. Although unique for flood protection, many countries have (legally binding) safety norms for external safety (e.g. airplane risks, chemical safety, and nuclear safety) often expressed as annual probability of death for individual persons.

Interestingly, the new norm in The Netherlands is not sensitive to sea-level rise scenario but is rather determined by the capital and people that are at risk from flooding (damages and loss of life). Loss of life is thus specifically taken into account, and for about 1/3 of the flood defences the loss of life criterion is the determining factor for the height of the new standards (Van der Most et al., 2016). For benefits and costs (costs include flood damages and investments in flood protection) an optimum is found (the marginal benefits of flood protection equal marginal costs of coastal defences). Therefore, socio-economic scenarios become very important, as the expected damages of protecting assets and people are determined by the (projected increase of) capital and people in the coastal locations, and the (increase in) expected damages determine the (increase in) required protection level (see graph, above). In The Netherlands, the required flood probabilities have now been established for individual stretches of flood protective infrastructure and have been accorded in parliament (see Water Law, 2016). Through a national programme of flood protection improvements, these standards are now implemented, using guidance on how to account for extreme river discharges and coastal water levels.

In Germany, absolute coastal protection standards have been adopted, generally with protection at levels of 1:100 years or more (Safecoast, 2008). For specific locations (e.g. city of Hamburg), these levels are higher, up to 1:400 years.

In the UK, decisions are made at two levels: at national and at local level. At both levels, flood risk management strategies must specify the objectives for managing local flood risk, the costs and benefits of those measures, as well as the assessment of local flood risk. In this process, the current risks minus future risks will define the benefits, and thereby a certain level of protection is chosen. The level is however not prescribed. These arrangements are part of the Flood Risk Regulations 2009 and the Flood and Water Management Act 2010, and are part of the implementation of the EU Floods Directive in the UK. At the national level, the national flood and coastal erosion risk management strategy for England describes that the Environment Agency (EA) has the role to lead development and improvement of the flood defence schemes (including dikes and reservoirs) for protection from rivers and seas. The EA works together with local flood authorities and local communities to determine the required levels of protection based on local priorities (EA, 2011, p. 32).

An alternative strategy to find optimal protection levels could be to select measures and design of coastal protection that have the minimum costs for protecting against a high or maximum sea-level rise scenario. This is called a minimising maximum regret approach. The regret here refers to the fact that the maximum sea-level rise scenario may not materialise, but the regret of high investments associated with this high scenario can be minimised. The actual costs of implementing of coastal protection plays an important role, as the fixed costs (for instance start-up costs, design, legal costs) associated with coastal protection projects in many cases are relatively high, compared to the costs of level of the protection works. So rather than having multiple projects over time in one location, one large project that is (slightly) over-designed, could be economically more attractive.

4.5 Practice of reporting of climate change under the EU Floods Directive

The current reporting round (Preliminary Flood Risk Assessment and Areas of Potential Significant Flood Risk; in 2015) did not yet require the inclusion of climate change or sea-level rise scenarios. Two of the countries studied (Netherlands and Germany) have not included climate change for the coast in their reports in this round. This conclusion is based on a quick scan of the reports (EIONET, 2017) for Germany (including relevant coastal catchments of the Elbe, Schlei/Trave, Ems, Eider, Peene). In the next reporting round for the Floods Directive (in 2018) this is however a requirement for all countries. The United Kingdom considered climate change (including sea-level rise) in their reporting for the Preliminary Flood Risk Assessment, until the year 2030 and 2050, However, the choices that are made for the scenarios described here are not clear. Also, the climate change effects have not been included in the flood hazard maps for the UK.

5 Summary and recommendations

The Danish Coastal Authority (DCA) is preparing for the second cycle of the implementation of the EU Floods Directive. Within this framework, the DCA aims to also determine the effect of climate change on the flood risk. The scenarios discussed in this memo mainly refer to sea-level rise scenarios, but may also include scenarios for changes in storminess and surge hazard. The effects of climate change have to be incorporated in the flood risk mapping, on the basis of which local municipalities will develop their risk management plans. The climate scenarios that will be used for the mapping will therefore be perceived by the municipalities as recommendations for which climate scenarios for new land and city development plans, new infrastructure, and adaptation plans for current flood protection structures can be based on.

To ensure a better basis for determining which climate scenarios and timeframes to use for risk mapping and risk management, this report provides an overview of best practices in neighbouring countries on including climate change in coastal risk management and urban development plans. This leads to the following conclusions and recommendations.

As the review above show, different countries have chosen different types of scenarios, including middle, high, and upper-end scenarios. These choices can support the analysis of flood risk as well as different investment decisions, and it is important to decide up-front which type of scenario is most appropriate for the question at hand. Scenarios can be used in awareness-raising, including middle range scenarios, as well as upper-end scenarios for informing what could be maximally at risk, and what protection efforts are maximally needed. For instance, for investments it may be wise to include high or upper-end scenarios in order to avoid under-investment or high costs when sea-level rise is more than anticipated, but for awareness raising middle range scenarios may be sufficient to sensitise local population and decision makers.

Apart from flood risk mapping, it may also be helpful to discuss what is an acceptable risk and thus required norm, or safety standard, for flood protection. Economic analysis on costs and benefits can help to find an optimum level. This flood probability in turn will define the design for specific hydraulic boundary conditions when implementing the coastal protection plans.
Next to defining protection levels, an alternative approach may be to establish the minimum of the costs associated with the measures for protecting against a high or maximum scenario, taking into account current uncertainties in sea-level rise and changes in storminess, and thereby avoiding to make an underinvestment (minimising maximum regret approach).

In addition to climate scenarios, socio-economic scenarios can be used to assess what is potentially at stake in the future, when population and urban areas on the coast increase. This can be an entry point for discussions with local stakeholders that aim to develop and protect their communities, on what scenarios and what changes in risk to consider in their work. Also, such analyse swill support to decide on required protection levels for a future point in time.

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