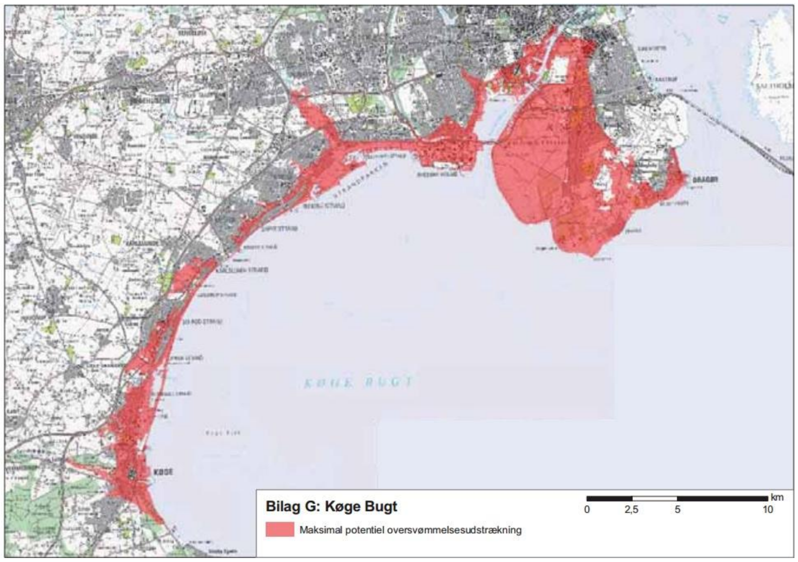

The Bay of Køge. The red area is the max extend of potential flooding (The Danish Ministry of the Environment & the Ministry of Transport, 2011b, p. 77).

Roskilde Fjord in 2013 during the storm 'Bodil'. The Viking Ship museum located at the harbor was flooded (Berlingske Tidende, 2013).

Conflicting methodologies of climate adaptation in a Danish context

The EU Floods Directive and the IPCC

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Abstract

This project applies two methodological prototypes, the Projection Analysis and Causal Chain Analysis, to make a comparative analysis of the methodologies behind the European Union Floods Directive and the Intergovernmental Panel on Climate Change, specifically in regards to sea level rise and floods attributed to climate change. In order to accomplish this comparison, a chapter has been dedicated to the physical basis of climate change, along with a chapter describing each of the two methodological approaches. Cases from the island of Zealand, Denmark are included as method-illustrations, as examples of adaptation plans and extreme weather events, to add a Danish context to the project. This project finds that the methodology behind the EU Floods Directive is an example of a semi-empirical model, which bases its projection of the future on past events. The method is simple and easy to implement, but it does not account for the fluctuations in the climate, which is inevitable under global climate change. The methodology of the IPCC is complementary to the process models, which are complex and includes a large range of variables, with the goal of simulating the processes found in the world. This method is difficult to comprehend and carries the risk of miscalculation in the many variables, but will provide a more detailed assessment. Lastly, this project has the objective of assessing the extent of which the two methodologies can be deemed successful.

Table of Contents

List of figures and tables

1. Introduction

This chapter will introduce the problem area and interest of this report, which will be narrowed down into a problem formulation and two working questions. The working questions will function as a structural aid throughout this paper. Secondly, the personal reasons and motivation for conducting this research will be described. This chapter will then offer characteristics of the study areas used as illustrations in order to contextualise the literary empirical material. This chapter will be concluded with some thoughts regarding the limitations of this research.

1.1. Problem area

> *Global climatic change and sea-level rise are the most striking manifestations of the impact of man on the ecological balance of our planet.*
>
> (Pier Vellinga in Tooley & Jelgersma, 1992, p. VII)

Climate change has arguably become one of the greatest environmental challenges of our time. The drastic increase in anthropogenic CO_2 emissions since the industrial period has led to an ever-growing focus on this topic by scientists, politicians and the media. We find that a change in the climate system has a generally encompassing impact on the Earth. Natural systems and societal structures, including technological development will be challenged by a changing climate. Climate change is a difficult measure, however, and future projections thereof are constantly under scrutiny.

Climate change can, however, be tangible as well: In Denmark, the Hurricane 'Bodil' was responsible of flooding large areas in the Municipalities of Frederikssund and Roskilde due to the massive storm surge associated with the storm. Sea level rise and flooding are inevitable consequences of increasing temperatures attributed to climate change.

It is a general trend that urbanisation near the coast is considered attractive. The majority of the so-called megacities[1] are situated near the coast (Martinez *et al.*, 2007 in Masselink & Gehrels,

[1] Megacity: *Cities with more than 8 million people* (Martinez *et al.*, 2007 in Masselink & Gehrels, 2014, p. 5)

2014, p. 5) and it is currently estimated that […] *23% of the global population currently live within 100km of the coast and less than 100m above sea level* (Masselink & Gehrels, 2014, p. 5). These increasing trends favouring coastal population (Small & Nicholls, 2003 in Masselink & Gehrels, 2014, p. 5) combined with the evident changes in future climate stress the imperative in addressing the issue of inevitable future flooding and the associated vulnerability of affected areas.

The European Union's Floods Directive from 2007 has tasked its Member States with the mapping of areas in risk of experiencing flooding due to sea level rises. The associated Member States then each have to compose plans for implementation in order to adapt and thus lower vulnerability against the impacts of future climate changes. In Denmark, the state has assigned the municipalities with the responsibility to devise these planning strategies. In total, 10 areas have been identified as risk areas in terms of flooding, all based on historical events (Municipality of Solrød, 2014a). The Bay of Køge is one of the areas that have been identified as high risk areas and the associated municipalities have as such been assigned with the task to work out adaptation plans. However, Roskilde Fjord and the Municipalities of Roskilde and Frederikssund were not appointed high risk areas as there previously had been no significant historical events in these locations. Utilising a methodology, which calculates the probability of risks involved with 10-, 100-, and 1000 year flood events, the municipalities ground their adaptation strategies on scenarios in a historical context, even though the climate is evidently changing and new areas end up as high risk areas - as seen with Roskilde Fjord.

A different actor within the field of climate change is the Intergovernmental Panel on Climate Change (IPCC). The IPCC has released several Assessment Reports on climate change, which have been a leading voice in the climate change debate. As such, changes within the IPCC's Assessment Reports impact initiatives, planning processes etc. made around the world regarding climate adaptation and mitigation, as these are widely used by governments and municipalities as a scientific support in order to assess future climate related challenges, and the need for the strategies required to adapt. In their 3rd Assessment Report (TAR), the IPCC suggested the need for a greater focus on adaptive capacity and vulnerability in order to better secure future capital against climate changes.

As such, two major players have developed two different methodologies for projecting future climate. The primary problem, which this project investigates, is therefore whether the way the climate is projected needs to be changes, as the climate is changing in ways never experienced before. If the climate adaptation plans are based on data accumulated from before anthropogenic climate change was a factor, the resulting plans will not be fully capable of its purpose: adapting to the future climate.

1.2. Problem formulation

The section above then brings the following problem formulation:

How can the methodologies of, respectively, the EU Floods Directive and the IPCC be compared, using two different prototypes of approaches regarding sea level rise attributed to climate change, in a Danish context?

To answer this, we have included the following working questions:

WQ 1: How do the EU Floods Directive and the IPCC propose to approach climate change, specifically in relation to flooding and sea level rise?

WQ 2: What are the main differences between the two methodologies and how can they be exemplified through the selected method-illustrations?

In this project, a method-illustration is a case example, where the methodologies in some way are illustrated. An example of a method-illustration is the Risk Management Plan from the Municipality of Solrød (part of the Bay of Køge).

An additional objective to this project is to use the problem formulation in order to make an assessment as to whether the two methodologies can be regarded as “successful”. The definition of success will be defined and further explained in the second chapter “Methodology” and the assessment will be made in the final conclusion.

1.3. Motivation

Climate change is happening, and learning about climate change has been on the agenda during all of our time in the educational system, in various fields. To understand the physical basis for climate change is paramount, and with that, the knowledge of how the future climate is calculated. We found that we lacked sufficient knowledge in these fields, but also in the processes of forming strategies of mitigation and adaptation to various problems related to climate change. Thus, this project was conceived.

During a visit to Greve Solrød Forsyning[2], Denmark, we discovered that preparations have been made for future changes in climate and how climate change might impact their capacity and efficiency in the municipalities. These preparations turned out to be a part of a national plan, originating in a directive from the European Union. This made us wonder how these plans created, that is, what kind of methodology was behind the plans.

1.4. Study area

Denmark is a small country of 43,000 km^2, and consists of one peninsula and 443 islands of various sizes. Except for a 140 km border to Germany, Denmark consists only of coastline, which collectively adds up to around 7,300 km of coastline (The World Factbook: Denmark). Denmark has a low altitude, thus not elevated much above sea level, as is evident from the figure below.

The combination of the quantity of coastline and the low altitude, as seen in Figure 1, puts Denmark at high risk of flooding from rising sea levels, compared to other EU nation-states. Germany, for example, only has 2,389 km of coast from its 348,672 km^2 land area (The World Factbook: Germany) and Austria has no coast at all.

[2] Greve Solrød Forsyning: Local utility and supply company.

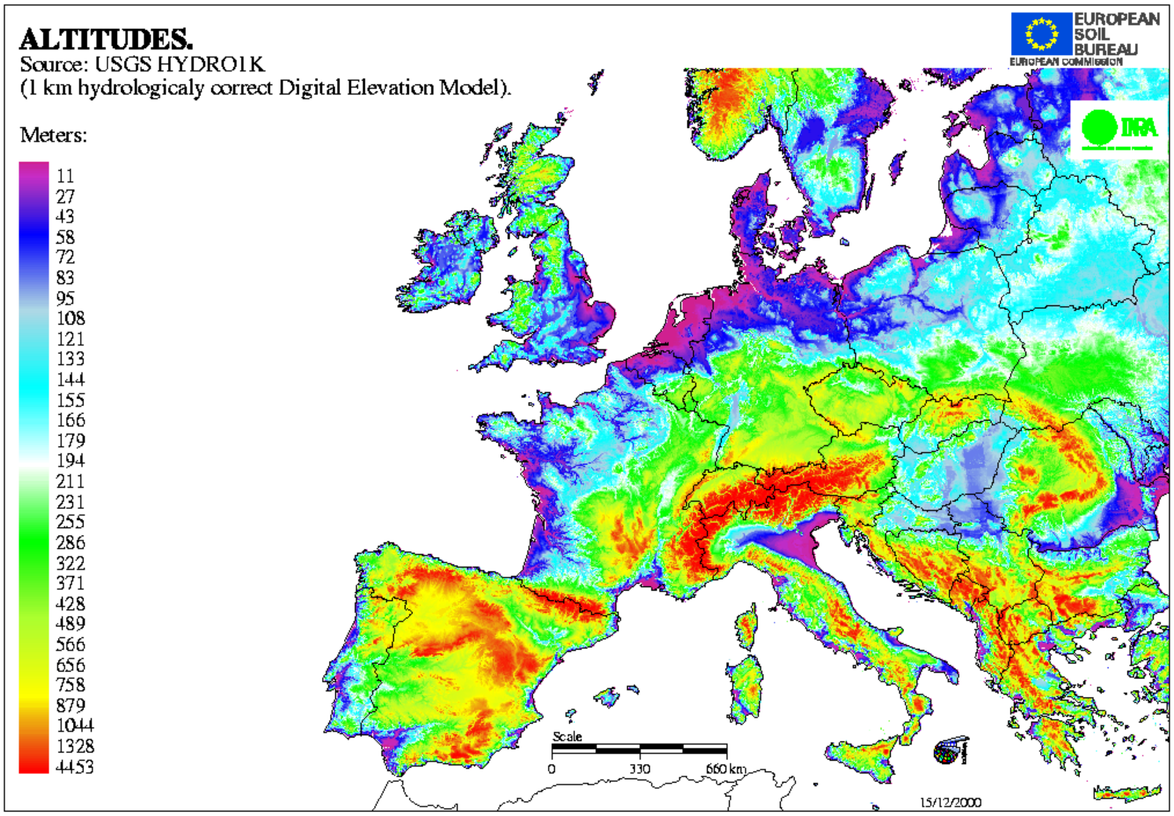

Figure 1: Altitudes in Europe (European Soil Bureau, 2000)

The Bay of Køge is located on the eastern part of the island of Zealand in Denmark. The catchment is 990 km2 and has a population of roughly 620,000. The coastal area from Copenhagen to Køge is highly populated, and the municipalities affected include Dragør, Tårnby, Copenhagen, Hvidovre, Brøndby, Vallensbæk, Ishøj, Greve, Solrød and Køge (The Danish Ministry of the Environment & the Ministry of Transport, 2011a, pp. 66-67). As figure 2 below shows, the Bay of Køge has been identified as a risk area in relation to the EU Floods Directive, making it an interesting case study due to its high population and its history of floods due to its low altitude.

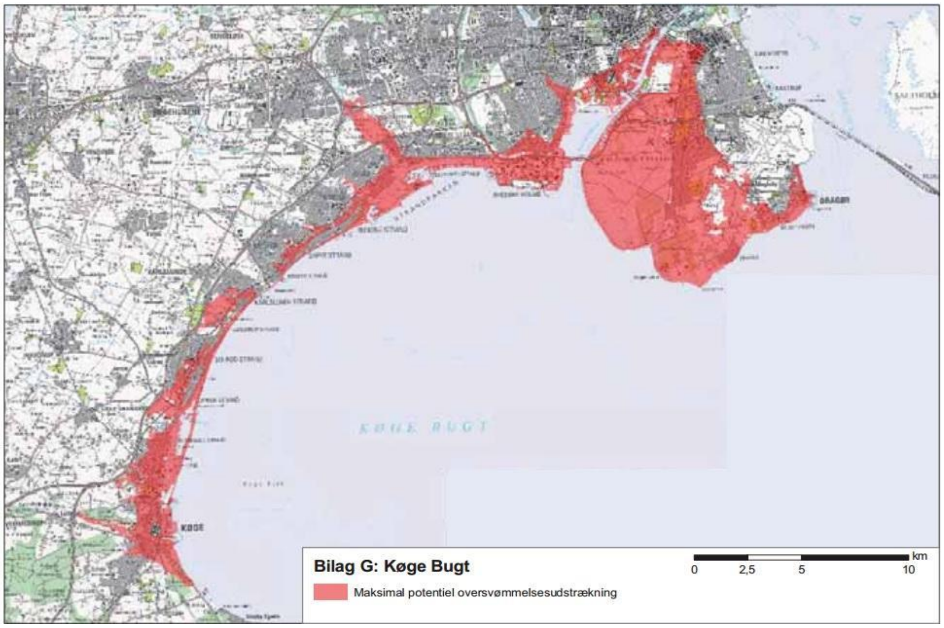

Figure 2: The Bay of Køge flood risk area (The Danish Ministry of the Environment & the Ministry of Transport, 2011b, p. 77)

Roskilde Fjord is the only fjord landscape in the Capital Region, and holds great recreational value both locally and to the rest of the region. It is a typical Zealandic fjord landscape, with a combination of narrow watercourses, small islands, and several islets. The water in Roskilde Fjord is very shallow, and tidal floats occur a few places, and along the coast there are salt meadows and wetlands (in Danish: "rørsumpe"). Furthermore, the fjord has several preservation areas for birds on the islands and islets (The Danish Nature Agency, 2010).

In December 2013, a storm surge, with water levels 2.06 metres above daily levels, flooded the harbour of Roskilde and residential areas near the fjord. In the harbour, the Viking Ship Museum and 20 residences were flooded, and in the residential area of Jyllinge Nordmark, around 200 residences were flooded (Municipality of Roskilde, 2014, p. 4). In addition to the harbour of Roskilde and Jyllinge Nordmark, the Municipality of Frederikssund was also flooded during the 2013 storm surge especially in the low altitude areas near the coast of Roskilde Fjord and Isefjord (Municipality of Frederikssund, 2014, p. 2). Roskilde Fjord and the Municipality of Frederikssund were not identified as risk areas in terms of flooding.

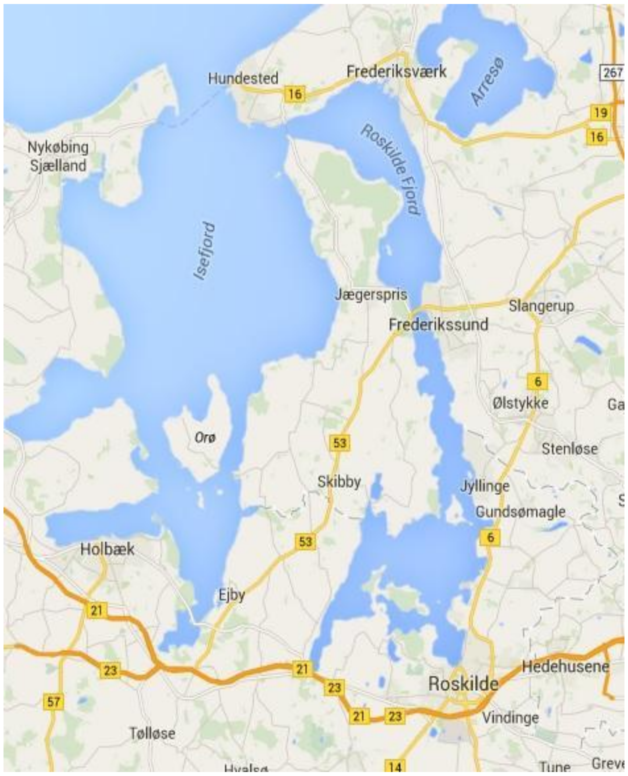

Figure 3: Roskilde Fjord (Google Maps, 2015)

1.5. Limitations

Due to both a limited time frame and in order to make the project manageable, we have chosen to limit the scope of this report and by doing so, excluding certain aspects within the field of research. The two methodologies of climate projection we are investigating cover large geographical areas (e.g. the entire European Union). Thus, we have limited ourselves to Denmark, more specifically certain areas of the coast of Zealand (the Bay of Køge and the Fjord of Roskilde).

Additionally, we limit ourselves by only focusing on the actual methodological approaches and their respective prototypes of both the EU Floods Directive and the IPCC. As seen in the figure 4 below, in its entirety the process of climate adaptation starts with the methodology, from which a strategy is formulated. The final step is the plan of action, where the concrete initiatives are put to use. The main focus of this report will as such not be on actual strategies, plan of action and implementation of climate change adaptation, although the cases of the Bay of Køge and Roskilde Fjord will be included as illustrations of the methodology.

Figure 4: Methodological limitation. This figure illustrates this project’s focus on methodologies. (Own making)

In relation to the philosophy of science of this report, we will not delve into the discussion about whether modelling and projection is possible and valid as true knowledge.

Additionally, this project will not go to depths with the management of extreme in-land precipitation events nor the behaviour of groundwater, but rather focus on flooding originating from the sea both from extreme weather-events and from the general rising sea levels.

If not limited by time, we would have liked to perform our own vulnerability and risk analysis on a given geographical location, to compare the results of the two methods.

2. Methodology

When starting the initial research for this project, one of the first issues we stumbled upon was how the government had identified the 10 locations in Denmark as being risk areas for flooding. What we were surprised to find was the fact that Roskilde Fjord was not identified, when taking into account that the entire area of both Roskilde and Frederikssund were heavily flooded by the storm ‘Bodil’ in early December 2013.

Therefore, there was a justified reason to suspect a problem with the way the risk areas in Denmark were identified. This led to the source for the sea level rise risk assessment methodology: the EU Floods Directive, and its comparable counterpart utilised by the IPCC.

This leads us to two issues: Firstly, how do you conduct a comparative analysis? Secondly, how can one compare these two methodologies?

2.1. Analytical strategy

In this project, we aim to make a comparative analysis of the methodologies as presented in the EU Floods Directive and in the TAR by the IPCC, and we will therefore have a comparative research design for our analysis. But what does a comparative research design entail and why is it useful?

A comparative design […] *entails studying two contrasting cases using more or less identical methods* (Bryman, 2012, p. 72). By carrying out a comparison of two or more cases, contrast and similarities are uncovered and the general phenomenon of which the study is about is more easily understood (Bryman, 2012, p. 58; 72). Additionally, a comparison can be used to […] *illuminate existing theory or generate theoretical insights* (Bryman, 2012, p. 710). As such, an important feature of a comparative analysis is […] *its ability to allow the distinguishing characteristics of two or more cases to acts as a springboard for theoretical reflections about contrasting findings* (Bryman, 2012, p. 75).

However, a problem with a comparative analysis can be that […] *the differences that are observed between the contrasting cases may not be due to exclusively to the distinguishing features of the cases* (Bryman, 2012, p. 74). Therefore, one must keep in mind that the contrasts found in a comparative analysis might originate from elsewhere.

So how does one go about writing a comparative analysis? The Harvard College Writing Center presents five steps for doing so:

1) Frame of Reference

The frame of reference is […] *the context within which you place the two things you plan to compare and contrast* (Harvard University, 1998). As such, the frame may consist of a problem (e.g. rising sea levels) from which one can extract two proposals for a solution (the EU Floods Directive and the IPCC). Additionally, the frame of reference must be based on solid sources or facts, rather than thoughts or observations to make a stronger case.

2) Grounds for Comparison

It is important to state the reason behind choosing the specific cases. Put differently, one needs to explain […] *the rationale behind your choice* (Harvard University, 1998).

3) Thesis

If effective, the thesis is a statement that represents an argument (Harvard University, 1998) and is dependent on how the two chosen cases compare to each other, e.g. the extent of which they contradict, support, or validate each other. Therefore, it is important to clarify the relationship between the two cases of the comparative analysis, no matter if the project focuses predominantly on differences or on similarities (Harvard University, 1998). As such, the problem formulation, or more precisely the working question 2, functions as the thesis, and can be considered as the premise of the comparative analysis.

4) Organisational Scheme: How to structure your analysis.

When writing the comparative analysis, there are two methods to organise and write the analysis: *text-by-text,* where one first discusses all of case A, then all of case B. Alternatively, one can write the analysis *point-by-point,* where one substitutes the points from case A with comparable arguments about case B. So which one to choose?

> […] *If you think that B extends A, you'll probably use a text-by-text scheme; if you see A and B engage in debate, a point-by-point scheme will draw attention to the conflict*
>
> (Harvard University, 1998).

As such, in the case of the methodology utilised by the EU Floods Directive and the IPCC, this project will utilise the *point-by-point* method of writing, as it better facilitates the discussion of how equipped the methodologies really are for projecting the future climate.

5) Linking of A and B

Of course, it is important to constantly refer back to the initial premise through the argumentation of the comparative analysis. If missing, both reader and writer […] *will be unable to see how new sections logically and systematically advance* [the] *argument* (Harvard University, 1998).

However, how were we to compare these two methodologies? This is where our methodological prototypes come in.

2.2. Methodological prototypes

The methodologies utilised by both the EU Floods Directive and the IPCC to make their analysis', are not easily defined because the organisations do not have chapters in their reports where they present any conceptual model as their methodology, nor how they might be wrong (though the IPCC illustrates the level of confidence). We have therefore designed two methodological prototypes, or archetypes, in an attempt to simplify how the two actors go about projecting and propose preparing for current and future climate changes. These prototypes and their respective links to the actual methodologies of both actors will be elaborated upon in the analysis.

The two prototypes are the Projection Analysis and the Causal Chain Analysis. The degree of which the two prototypes fit the methodologies of the EU Floods Directive and the IPCC will not be discussed here. Instead, the basic idea behind the two prototypes will be presented.

2.2.1. Projection Analysis

The idea behind the Projection Analysis is simple, which is in part its weakness, but also a reason behind its attractiveness in praxis. The present baseline, which is the base of reference for comparison, is determined by previous events, dating from decades to millennia, and is used to make a projection for the future baseline.

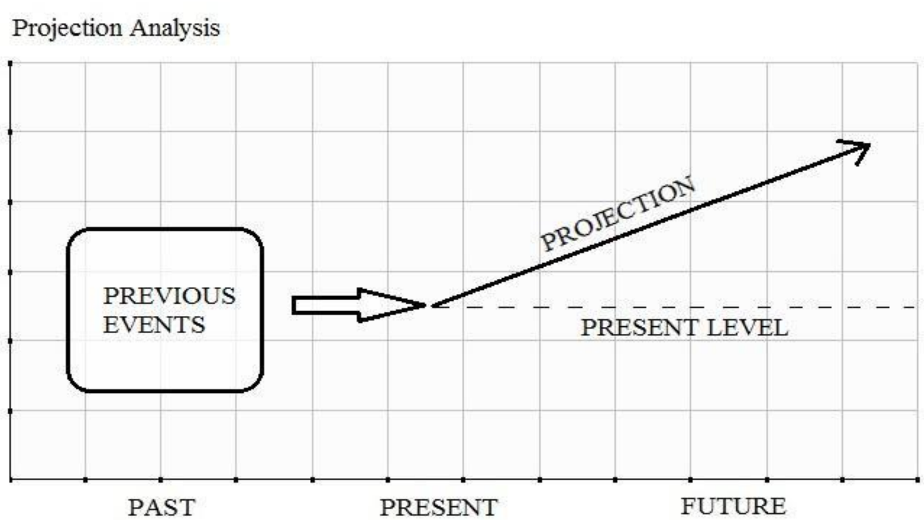

Figure 5: Methodological trajectory of the Projection Analysis. (Own making)

2.2.2. Causal Chain Analysis

The Causal Chain Analysis is more complex. This, as with the Projection Analysis, is both a weakness and strength. This subchapter will introduce the methodological prototype of the Causal Chain Analysis (CCA) as presented in the Global International Waters Assessment (GIWA). GIWA's methodological approach was created specifically in order to be able to compare with the methodological approach of the IPCC and is thus relevant to this research report.

2.2.2.1. What is GIWA?

The Global International Waters Assessment (GIWA) was created in 2002 due to a lack of an international waters assessment, to compare to that of the IPCC, the Global Biodiversity Assessment (created by UNEP in 1995), and the Stratospheric Ozone Assessment (created by UNEP and the World Meteorological Organisation (9th edition from 2014)). The lack of such an assessment meant severe impediment to the implementation of the International Waters Component of the Global Environment Facility[3] (GEF), since there was no basis on which to identify areas of global priority for GEF intervention (GIWA, 2002, p. 3). As a result, […] *GIWA was created with the overall objective of developing a comprehensive, strategic framework for the identification of priorities for remedial and mitigatory actions in international waters, designed to achieve significant environmental benefits, at national, regional and global levels* (GIWA, 2002, p. 3).

2.2.2.2. The Assessment Framework and the Causal Chain Analysis

GIWA consists of a composition of different sub-regional assessments of the ecological status of international waters, the causes of their degradation, and the policy options available to improve their status, made by groups of specialists on a sub-regional level, all following a common methodology. Upon combining the areas investigated by the groups, a global picture emerges, which is GIWA (GIWA, 2002, p. 3).

The Assessment Framework contains five components: Scaling, Scoping, Detailed Assessment, Causal Chain Analysis, and Policy Option Analysis (GIWA, 2002, p. 3).

This project will be examining the Causal Chain Analysis (CCA) component of the Assessment Framework.

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[3] The Global Environment Facility (GEF) was established in October 1991 by the World Bank to aid in the protection of the global environment and to promote environmental sustainable development. The World Bank along with the United Nations Development Programme (UNDP) and the United Nations Environment Programme (UNEP) were the first initial partners to implement GEF projects. In 1994 the GEF was made an independent organisation, separate from the World Bank. Today, 183 countries work together with international institutions in the partnership that is the GEF (http://www.thegef.org/gef/whatisgef).

> *Causal Chain Analysis traces the cause-effect pathways, associated with each significant concern, from the socio-economic and environmental impacts back to its root causes. Its purpose is to identify the* <u>*most important*</u> *root causes of each concern, in order to target them by appropriate policy measures for remediation or mitigation*
>
> (GIWA, 2002, p. 16).

Thus, the overall objective of the GIWA CCA is to create a conceptual, strategic framework for identifying priorities for actions of alleviation and mitigation in international waters, through identifying and understanding the root causes of transboundary water problems, based on accepted theoretical models (GIWA, 2002, p. 16).

The GIWA CCA identifies the factors that shape actions which either directly or indirectly impact GIWA's issues and concerns, and they are identified using the Scaling and Scoping Methodology (listed in the Annex III on page 32 of the GIWA Methodology Report). These factors are then used to identify […] *the root causes of human actions that impact the way in which water and water related resources are used* (GIWA, 2002, p. 16). The complexity of these causal factors makes it difficult for a nomothetic forecasting model to be built. However, measurable and quantifiable evidence should be given in support of the conceptual model (GIWA, 2002, pp. 16-17) and, also, in order to justify [...] *decisions to establish causal links* (GIWA, 2002, p. 17).

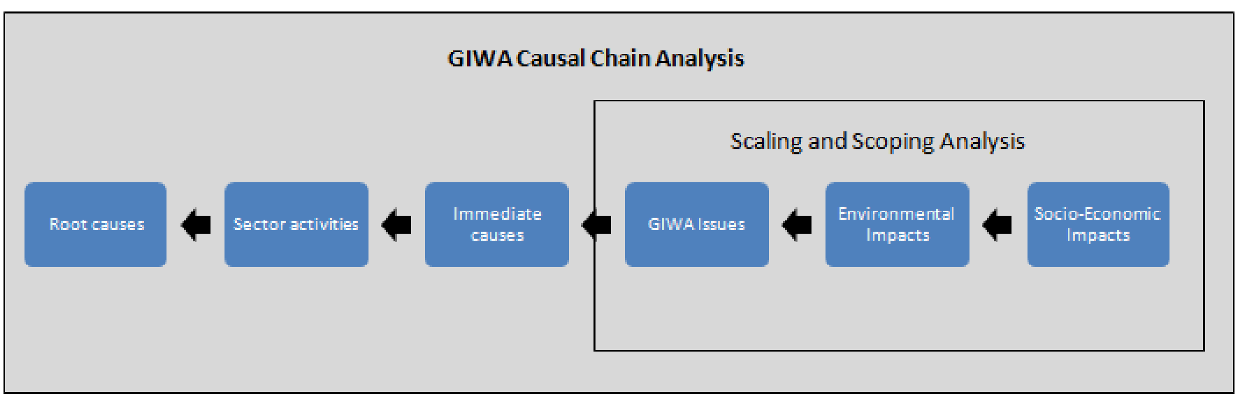


Figure 6: Inspired by GIWA's Causal Chain Analysis (Own making inspired by GIWA, 2002, pp. 17-18)

Figure 6 shows how the CCA attempts to identify the root causes to undesirable impacts and issues by linking them through immediate causes and sector activities. As such, the cause-effect pathways can spread out and the process of identifying causality becomes a matter of many different factors.

Thus, it is clear that the Causal Chain Analysis methodology, under which flood risks can be categorised, is a complicated measure. It is subject to several influences, which in turn are affected by other factors, therefore resulting in complex cause-effect pathways. As mentioned in the beginning of this subchapter, the specific methodology of the IPCC will not be explained here, but later in the project (see chapter 4.2), however, it can be revealed that similar complex processes are included.

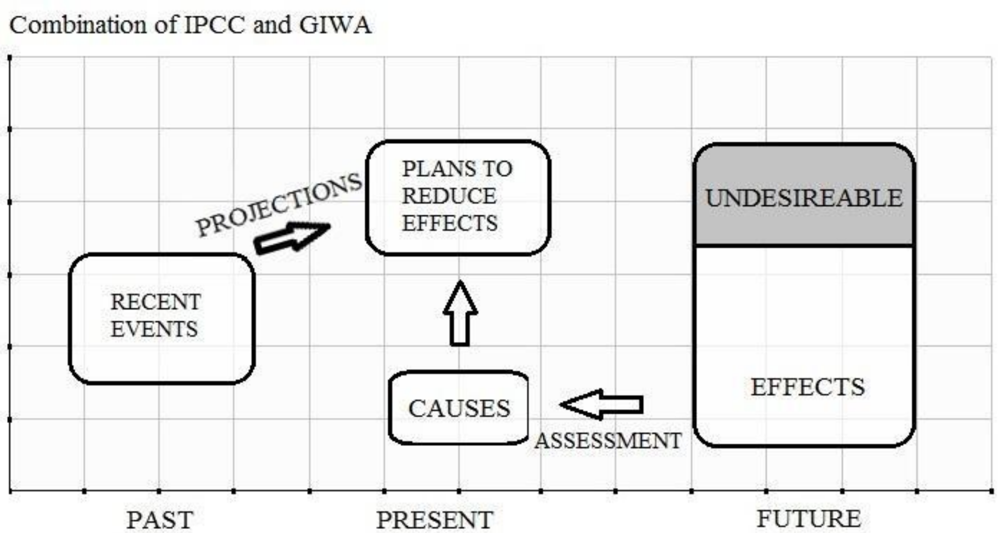


Figure 7: Methodological trajectory of the IPCC and GIWA Causal Chain Analysis. (Own making)

As figure 7 demonstrates, the GIWA CCA function as our prototype for the IPCC methodology, which will be elaborated upon in chapter 4.

2.3. Basis of evaluation

The two prototypes will be evaluated on the basis of the criteria for assessing successful adaptation. Thus, the criteria are used to evaluate whether the methodological prototypes are successful and relevant tools for forming adaptation strategies. However, specific adaptation strategies and our method-illustrations will not be evaluated, since the project focuses on the methodological aspect of climate change, as mentioned in chapter 1.5..

Loë *et al.* (2001, p. 232) identify three different measures of adaptation. Firstly, *accepting losses* is typically shared across the scale of individuals and groups. Secondly, *preventing effects* refers to engineering of pre-emptive measures to avoid the consequences of climate change. Thirdly, *changing uses and/or locations* involves the acknowledgment that previous uses of a given location cannot be pursued beyond the impacts of climate change.

Adger *et al.* (2004) argue that successful adaptation is defined by five components: the criteria for success, effectiveness, efficiency, equity and legitimacy, and, finally, in evaluating success. Ultimately, successful adaptation and its resulting measures must be considered in their spatial and temporal scale. Spatially, adaptation in one area may have impacts on other spaces. Temporally, an efficient adaptation implemented today may not be efficient in 20, 50 or 100 years. As such, the more robust and flexible an adaptation is, the more effective it is in turn. In terms of efficiency, the economic costs and benefits must be evaluated and the related timing of implementation. Equity and legitimacy largely relates to the ethics and values of an adaptation and those who are affected in the process (Adger *et al.*, 2004, pp. 80-84). Values, however, can be diverse and, much like effectiveness depends on the scale in question. In evaluating the success of adaptation, it essentially comes down to the adaptive capacity of the related components and the robustness of the intended implementations. The robustness of adaptation can be identified in some key criteria: no regrets; reversibility; minimising environmental impacts; cost effectiveness; equity; reducing vulnerability; ease of implementation; and effectiveness (Loë *et al.*, 2001, p. 241).

Successful adaptation can thus be achieved through increasing the adaptive capacity and, in turn, reducing vulnerability against adverse consequences. The more robust and flexible the strategy is, the better the adaptation will be in a given location. Here, robust and flexible is accomplished using the aforementioned criteria offered by Loë *et al.* (2001), where spatial and temporal differences are taken into account.

2.4. Use of empirical material

This research paper will make use solely of secondary literary material in form of: academic texts, such as scientific articles, research papers and textbooks, legislative publications and public climate adaptation plans. This paper will not incorporate primary empirical material such as fieldwork, interviews and surveys. The aim of the project is, as such, to analyse and discuss the problem using literary empirical material and existing processes.

3. Basis of Climate Change

This chapter will provide the necessary knowledge about the current and projected future changes occurring to the climate. Firstly, this chapter will address the general natural science behind climate change. Secondly, the chapter will distinguish between flooding and sea level rise in relation to global climate change. Finally, this section will shed light on projections and models. Here, process models and semi-empirical models will be introduced as conceptual models relevant to the methodologies studied throughout this report.

3.1. The physical basis of climate change

This section will explain the science behind climate change and its effect on weather. In addition, the positive feedback loop will be utilised to emphasise the severity of the effect of climate change.

The composition of Earth's atmosphere is highly influenced by the biosphere, of which plants, animals and humans are a part, which in turn is highly dependent on the atmosphere. The atmosphere of current day is composed of 78.1 percent nitrogen (N_3), 20.9 percent oxygen (O_2), and 0.035 percent carbon dioxide (CO_2) (Holden, 2012, p. 77). However, scientific evidence indicates that the climate of the Earth is changing faster than expected, due to human activity emitting anthropogenic greenhouse gasses into the atmosphere, such as CO_2, and the CO_2-equivalents, methane (CH_4), nitrous oxide (N_2O) (Holden, 2012, p. 77 + 702), and ozone (O_3) (Withgott & Brennan, 2009, p. 285).

The greenhouse gasses and water vapour traps heat from the Sun near Earth's surface, causing the temperature at the surface to rise (Holden, 2012, p. 702). In effect, the elevated temperature then causes an increase in water evaporation from soil, oceans, lakes, and streams, which then causes even more heat to be trapped, due to the fact that water vapour is a greenhouse gas like CO_2 (DMI, 2014, p. 13). This is known as a positive feedback loop, which is an effect in which a systems reception of input creates an output that serves as a further input, thus driving the system further and further towards the extreme. Unless initiatives of mitigation are adopted, the system and consequences can spiral out of control (Withgott & Brennan, 2009, p. 49-50). When the system of the hydrological cycle are subjected to positive feedback, precipitation patterns are altered, making rainfall less frequent but more intense (DMI, 2014, p. 13).

Rising global temperatures also has an effect on sea levels and is an ultimate driver of coastal change (Masselink & Gehrels, 2014, p. 15). Today, water, equivalent to 75 metres of sea level rise, is stored in glaciers and ice sheets. When the surface temperature of the Earth rises, glaciers and ice sheets, which store large amounts of water on land, begin to melt, adding additional water to the ocean, causing the sea level to rise. As the glaciers and ice sheets melt, the Earth loses some of its Albedo effect, which is […] *a measure of the reflecting power of a surface* […] (Holden, 2012, p. 87), since ice has a high albedo compared to ice-free land and open water. If the albedo of Earth's surface decreases, additional solar radiation will be absorbed by the surface rather than being reflected back, and the surface temperature of the Earth will increase. This, in turn, will cause even more glaciers and ice sheets to melt, and the albedo effect to decrease even further, creating a positive feedback loop (Holden, 2012, p. 87-88 + 467).

In addition to melting the glaciers and ice sheets, rising temperatures also warms up the seawater, causing it to expand. This is known as thermal expansion. The expansion of the seawater raises the global sea levels, producing a so-called thermosteric sea level rise (IPCC AR4 10.6.1, 2007). While sea level change and flooding is the main interest of this research paper, there are other factors that affect coastlines due to climate change. Increasing global temperatures of the oceans leads to [...] *ocean acidification, changes storm patterns, and increases precipitation with major effects on coastal systems* (Masselink & Gehrels, 2014, p. 15).

3.2. Difference between flooding and sea level rise

It is important to distinguish between a flood event and the rise of the global sea level. In this project, we deal with both terms, as both are results from the changing climate.

3.2.1. What is a flood?

A flood is when […] *water overflows its natural or artificial banks onto normally dry land* (Encyclopædia Britannica, 2014). This can happen e.g. when a river overflows or when the wind presses the seawater onto shore in a storm surge. The EU Floods Directive also adds to this definition, that the covering of land by water, where it usually is dry, is only a temporary event (Directives, 2007 p. 3), thus the water will fall back eventually.

3.2.1.1. Types of floods

Table 1, made by the European Exchange Circle on Flood Mapping (EXCIMAP), shows several types of flooding, with the original cause of the flood (e.g. storm surge), the associated effects (e.g. water where there should be no water), and relevant parameters (e.g. how much water and how fast it moves).

Table 1: Types of Flooding (EXCIMAP, 2007, p. 10).

Type of flooding	Causes of flooding	Effect of flooding	Relevant parameters
River flooding in flood plains	• Intensive rainfall and/or snowmelt • Ice jam, clogging • Collapse of dikes or other protective structures	• Stagnant or flowing water outside the channel	• Extent (according to probability) • Water depth • Water velocity • Propagation of flood
Sea water flooding	• Storm surge • Tsunami • High tide	• Stagnant or flowing water behind the shore line • Salinisation of agricultural land	• Same as above
Mountain torrent activity or rapid run-off from hills	• Cloud burst • Lake outburst • Slope instability in watershed • Debris flow	• Water and sediments outside the channel on alluvial fan; erosion along channel	• Same as above; • Sediment deposition
Flash floods in Mediterranean ephemeral water courses	• Cloud burst	• Water and sediments outside the channel on alluvial fan • Erosion along channel	• Same as above
Groundwater flooding	• High water level in adjacent water bodies	• Stagnant water in flood plain (long period of flooding)	• Extent (according to probability) • water depth
Lake flooding	• Water level rise trough inflow or wind induced set up	• Stagnant water behind the shore line	• Same as above

As mentioned in a previous chapter, this project will not deal with precipitation in general, nor rivers, lakes or groundwater. There are no mountains in Zealand to speak of (or in Denmark in general), and the floods in the Mediterranean are also of little interest in this specific project. What *is* interesting, however, is the seawater flooding. As visible in the map below, Denmark is situated out of the tsunami hazard zone, so that specific cause of flooding can be disregarded.

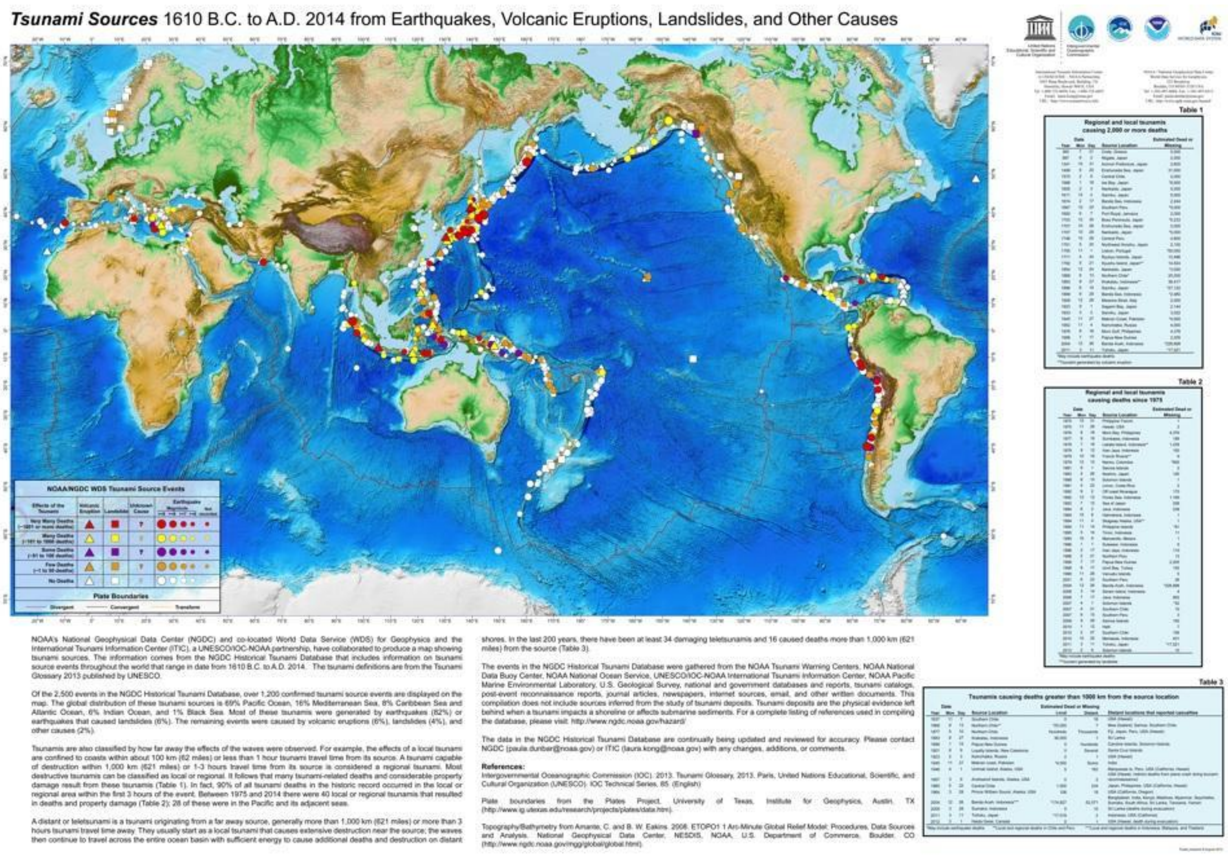


Figure 8: Tsunami Sources (ITIC UNESCO, 2014)

As such, what is left for the cause of seawater flood, are storm surge and high tide.

3.2.2. What is sea level rise?

There are two causes for global seawater rise, and both are linked to the rising global temperatures. Firstly, when water is heated it expands slightly. As visible in figure 9 below, the global seawater temperature is increasing:

Figure 9: Ocean Heat Content, 1955-2013 (EPA, 2014a)

Secondly, as a result of rising temperatures, the amount of water stored as ice (mostly as glaciers and ice sheets) is decreasing, thus increasing the volume of water in the ocean. This mechanism can also go the other way around, where the amount of stored water as ice increases, thus decreasing the volume of water in the ocean. However, according to the United States Environmental Agency, global seawater level of the entire world's oceans has risen annually at an average rate of 0.15 cm from 1880 to 2012, as visible in figure 10 below. Since 1993, however, the sea level has increased by a rate of 0.28 to 0.31 cm annually, which is a doubling of the long-term trend (EPA, 2014b).

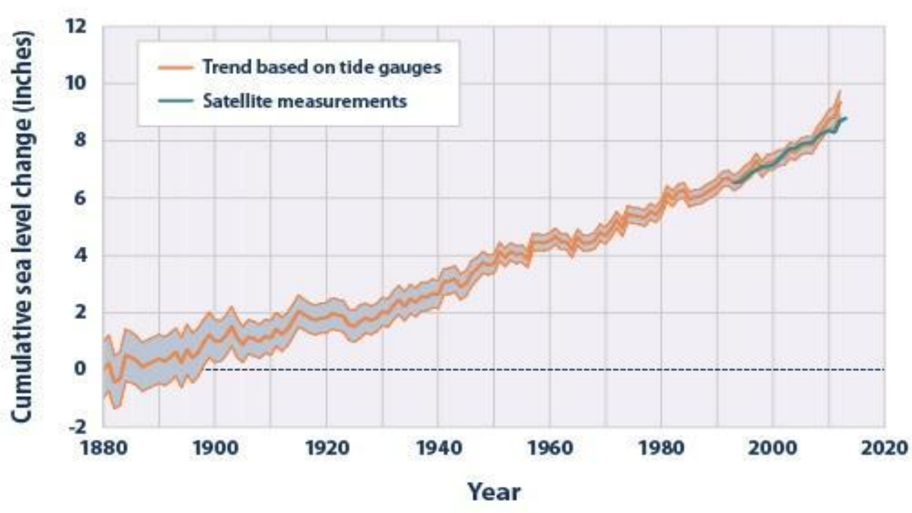


Figure 10: Global Average Absolute Sea Level Change, 1880-2013 (EPA, 2014b)

This above figure 10 refers to the *absolute* sea level change, which describes […] *the height of the ocean surface above the center of the earth, without regard to whether nearby land is rising or falling* (EPA, 2014b). A different way to measure changes in sea level is the *relative* sea level change, which incorporates the rising and falling of the land at a specific location (EPA, 2014b).

What to keep in mind when assessing impacts of sea level rise is that [...] *it is the local change in relative sea level that matters, not the global average* (UNEP, 1998, p. 180). As such, it is the relative, or observed, change in sea level that is the focus. The relative sea level rise is, according to UNEP, defined as [...] *the sum of global sea-level rise, regional oceanic effects, and vertical land movements* (UNEP, 1998, p. 196), and can be expressed by the following equation:

$$S_{r,t} = S_{g,t} + S_{o,t} + V \times t$$

where: $S_{r,t}$ = relative sea level rise in year *t* (m),

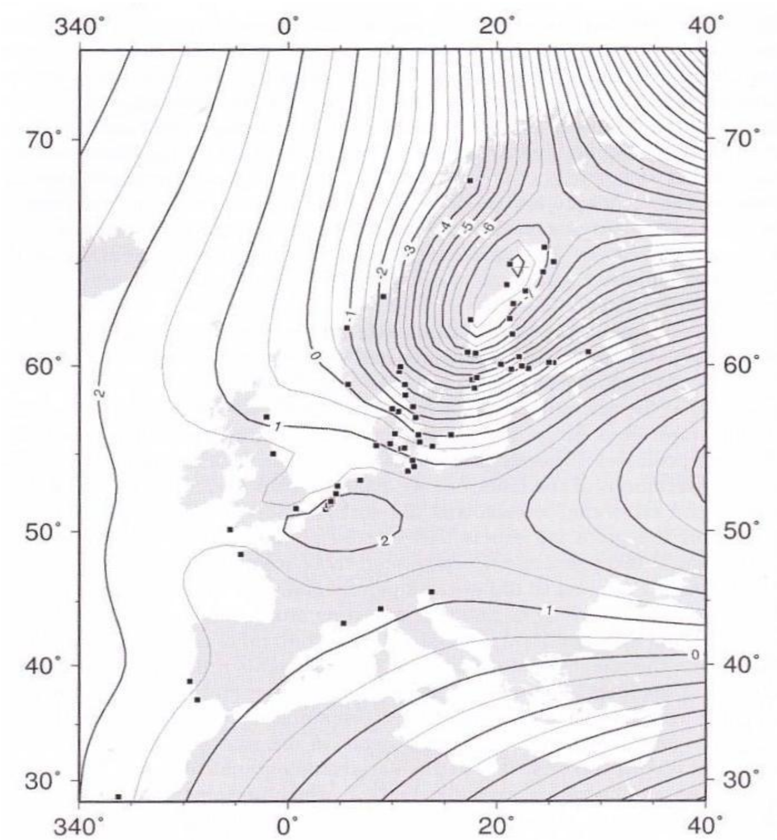
$S_{g,t}$ = global sea level rise in year *t*,

$S_{o,t}$ = regional sea level change induced by oceanic changes in year *t* (in metre),

V = vertical land movement (metre/year), and

t = number of years in the future (base year 1990)

(UNEP, 1998, p. 196).



An example of why the relative sea level rise can be of importance can be seen in figure 11 to the left. The figure shows changes in sea level trends (mm per year) in 20th century Europe, where it is shown how most of Scandinavia (except Denmark) and the Baltics have decreasing sea levels. This is the result of the Fennoscandian ice sheet, [...] *whose weight caused the earth underneath it to sink* (Douglas *et al.*, 2001, p. 5) generating the observed fall in relative sea level, as the area is still rebounding (Douglas *et al.*, 2001, p. 5).

Figure 11: Contour plot of 20th century European sea level trends (mm/yr) (Douglas *et al.*, 2001, p. 6)

Regarding coastal zones, as is the focus of this project, there are other changes to the climate, which can have compelling effects, [...] *such as changes in wind direction and intensity* (UNEP, 1998, p. 198). However, according to UNEP, these changes are as of yet highly uncertain, and are not a part of the focus of this project, as also described in the subchapter 1.5..

3.3. Projections and models

So now, the basics of climate change have been described, but before we go further on, it is relevant to elaborate a bit on what projections and models are all about, in the context of changing sea levels.

Projections are […] *model-derived estimates of future climate that are linked to defined forcing stories (e.g. the change in solar radiation, in greenhouse gases, in land-use disturbances)*

(McGuffie & Henderson-Sellers, 2014, p. 98). It is important to note that 'projection' is something different than 'predictions', as […] *a prediction is a single estimate with a quantifiable uncertainty; a projection is an estimate that is based on a specific assumption related to a necessary model input* (Masselink & Gehrels, 2014, 46). In the given context of changes in sea level, it is not possible to make an accurate *prediction* of e.g. future concentrations of greenhouse gas concentrations in the atmosphere, as this would is influenced by a range of factors (i.e. political and technological) […] *that are inherently unpredictable* (Masselink & Gehrels, 2014, pp. 46-47). This is why, when it comes to future changes regarding the climate, including sea level, projections are utilised with the help of various greenhouse gas concentration scenarios (e.g. those proposed by the IPCC).

Therefore, projections are based on models. Models are simplified representations of the physical world, however, [...] *the degree of abstraction (or its reverse: the level of complexity) varies hugely amongst models* (Masselink & Gehrels, 2014, p. 18). In general, models are used […] *to produce a quantitative estimate of how sea level will change in the coming decades to centuries* (Masselink & Gehrels, 2014, p. 46). In the case of projecting global mean sea level, there are, according to Masselink & Gehrels, two classes of models for doing so:

Process models, which are somewhat complex, attempt to simulate the given processes (e.g. ocean temperatures or the accelerating melting of ice caps and the resulting effect on the sea level). As Masselink & Gehrels puts it: […] *realistic modelling is notoriously difficult* (Masselink & Gehrels, 2014, p. 17), but the process models (as exemplified by the IPCC) are considered to include more factors than its counterpart, which are: *semi-empirical models.* Predominantly, the IPCC projection are on a global scale, and must, as such, […] *be downsized to a regional scale that is of practical use to coastal planners and managers* (Gehrels & Long, 2008 in Masselink & Gehrels, 2014, p. 17).

Semi-empirical models circumvents the complexity of process models as they do […] *not attempt to simulate the processes but, instead, applies a semi-empirical relationship based on past observations of sea level and temperature* (Masselink & Gehrels, 2014, p. 49). These past observation can be derived from the recent past (decades) or from millennia ago, and are consequently utilised to make projections for the coming century (Masselink & Gehrels, 2014, pp. 17-18; 47-49).

So how is this relevant for the rest of this project? The process model and semi-empirical model will be used when the two methodological approaches (from the EU Floods Directive and the IPCC) are compared when answering the second working question of this project.

4. Working question 1: The EU and IPCC Methodologies

In order to answer our first working question; *How do the EU Floods Directive and the IPCC propose to approach climate change, specifically in relation to flooding and sea level rise?*, we have made two sections: one about the EU Floods Directive and its utilisation of the term risk, and one about the IPCC. In the section on the IPCC, we elaborate on the climate scenarios and the terms adaptive capacity, vulnerability and risk. The chapter ends with a conclusion.

4.1. The EU Floods Directive

This section will account for the EU Floods Directive in relevance to this paper. The aim of the EU Floods Directive and the steps for implementation will be explained, and the concept of "Risk" will be considered. Finally, the EU Floods Directive will be put into a Danish context, in sake of the scope of this report.

The "Directive on the assessment and management of flood risks" was initiated by the European Union and approved for practice on September 18 2007. The EU Floods Directive (EFD) [...] *aims to reduce the adverse consequences on human health, the environment, cultural heritage and economic activity associated with floods in the Community* (EXCIMAP, 2007, p. 5). Based on these aims, Member States of the EU were required to firstly compile a flood risk assessment and select the areas that would be the focus of the following work, due in 2011. Secondly, Member States were required to present flood mapping of the selected areas assessed to be in high risk of flooding, due in 2013. Finally, Member States were required to compose flood risk management plans based on the flood mapping, due in 2015 (EXCIMAP, 2007, p. 5).

4.1.1. Risk

As aforementioned, the first step of the implementation of the Directive requires Member States to conduct a "Preliminary Flood Risk Assessment". They should do this for every river catchment, including topographical characteristics and land-use mapping. Furthermore, the risk assessment should include evaluations of past flooding events, which are deemed to have had adverse impacts on the current aims of the EU Floods Directive (Directives, 2007, p. 30). The second step, "Flood Hazard Maps and Flood Risk Maps", are based on the mapping of areas that could be flooded based on the following scenarios:

> *(a) floods with low probability, or extreme event scenarios;*
> *(b) floods with a medium probability (likely return period ≤100 years);*
> *(c) floods with a high probability, where appropriate.*
>
> (Directives, 2007, p. 30)

The Flood Hazard Maps and Flood Risk Maps are distinguished, where the former is defined to [...] *include historic as well as potential future flood events of different probability* [...] and must present [...] *flood extent, the water depths or water levels, as appropriate, and where appropriate the flow velocity* [...] in accordance with each of the scenarios surrounding the probability of the flood event (EXCIMAP, 2007, p. 17). As such, the methodological framework to create the preliminary flood risk assessment and flood hazard/risk maps were created by the EU Floods Directive and administered to the Member States to execute. The aims and goals of the Directive are binding to all Member States and must be implemented by a set a deadline. However, the EU cooperation [...] *shall leave to the national authorities the choice of form and methods* (The Danish Parliament, 2008). Therefore, Member States such as Denmark must follow the Directive, but they decide for themselves which methods to use and how to actualise it.

The Flood Risk Maps encompass the concept of risk. Here, the EU Floods Directive defines flood risk as [...] *the combination of the probability of a flood event and of the potential adverse consequences to human health, the environment and economic activity associated with a flood event* (Directives, 2007, p. 29). Thus the concept of risk can be summarised in a simple equation:

$$Risk = C \times Ph$$

where risk is the potential loss of a geographical area within a given period of time. Where C is the *potential adverse consequences* and Ph is the probability of the flood event (EXCIMAP, 2007, p. 23).

EXCIMAP (2007) further shows how C can be derived using the following equation:

$$C = V \times S(m_h) \times E$$

where V is the value of the factors associated with the risk. S is susceptibility, or damaging effect ranging from 0 to 1. E is the exposure of the factors at risk, ranging from 0 to 1 (EXCIMAP, 2007, p. 23).

Thus, the EU Floods Directive utilises the historically derived probability scenarios from the Flood Hazards Maps in combination with the vulnerability parameters of the aforementioned adverse consequences. The EU Floods Directive essentially grounds its use of vulnerability on historical flood events (Directives, 2007, p. 31; EXCIMAP, 2007, pp. 23-25).

Finally, the last step, the "Flood Risk Management Plans", which should focus on the factors of prevention, protection and preparedness, based on the previous steps of Flood Hazard and Flood Risk mapping, thus grounded in past flood events (Directives, 2007, p. 31). Therefore, the plans are composed under the assumption that historical flood events are still valid under climate change.

4.1.2. The Danish context

The implementation of the EU Floods Directive in Denmark is expected to occur in the duration of three phases:

Phase 1: Preliminary Flood Risk Assessment - evaluation and selection of high risk areas.

Phase 2: Flood Hazard Maps and Flood Risk Maps.

Phase 3: Flood Risk Management Plans (The Danish Coastal Authority, 2013, p. 6)

The Danish government has thus adopted this directive for implementation, whereby past events and their respective probabilities of occurrence have been utilised in order to select geographical areas in high risk of flooding (The Danish Coastal Authority & The Danish Nature Agency, 2014, pp. 14; 21-22). Here, the Danish Coastal Authority uses the general assumption that Denmark will experience sea level rises of 0.3 meters by 2060, and has selected 10 areas that are deemed in risk of flooding: Holstebro, Randers Fjord, Juelsminde, Vejle, Fredericia, Aabenraa, Odense Fjord, Køge Bugt, Korsør, and Nakskov (The Danish Ministry of the Environment & the Ministry of Transport, 2011b, p. 7). The selection of these areas and the potential for future flooding does not account for an increase in quantity and severity of storms, nor a change in precipitation due to climate changes. The selection of the aforementioned areas assigned high flood risk is based only on the projected future general sea level rise of 0.3 meters (The Danish Ministry of the Environment & the Ministry of Transport, 2011b, p. 17).

The Danish government uses the same concept and understanding of risk as described in the EU Floods Directive. According to the Danish Ministry of the Environment and the Ministry of Transport, both of which are responsible for the Danish mapping of Flood Hazard Maps and Flood Risk Maps, two factors are needed in order to determine any flood risk: the probability of a flooding event and the potential adverse consequences to humans and their valuable (The Danish Ministry of the Environment & the Ministry of Transport 2011b, pp. 18-19). Thus, the concept of food risk can, also in a Danish context, be summarised in the aforementioned equation used by the EU Floods Directive.

The Danish government has as such utilised past flooding events in combination with the projected future sea level rise of 0.3 meters as well as topographical maps in order to determine the actual flood risk, and, in turn, select the 10 locations mentioned previously in this section (The Danish Ministry of the Environment & the Ministry of Transport, 2011b, p. 24). Thus we find a tendency toward projection analysis and the usage of semi-empirical models (subchapter 3.3.) by the Danish government, where past events and current terrain are mathematically forced, perturbed with a 0.3 metre assumed sea level rise. It is, as such, a condition to this method that there will be no change in terrain (Municipality of Solrød, 2014a, p. 8).

4.2. The IPCC

The Intergovernmental Panel on Climate Change was established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO) as the issue of climate change became increasingly apparent. Three so-called Working Groups were initiated, responsible of compiling information for publication in each of their designated areas: Working Group I deals with the physical science basis of climate change. Working Group II is concerned with Impacts, Vulnerability and Adaptation. Finally, Working Group III is charged with Mitigation of climate change (IPCC, 2008-2014). The most recent IPCC Assessment Report as of this project is the AR5, the 5th Assessment Report. The comprehensive Synthesis Report of the AR5, including material from all three Working Groups, was released in 2014. Previous Assessment Reports were published in 1990, 1996, 2001 and 2007.

4.2.1. Climate Scenarios

Until the IPCC's Third Assessment Report (TAR), the method of developing climate scenarios had been largely ignored (IPCC TAR WG2 3, 2001, p. 163). Now, however, the IPCC consistently utilises climate scenarios to assess future climate change.

> *A climate scenario is a plausible representation of future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change*
>
> (IPCC TAR WG1, 2001, p. 741).

Thus, a climate scenario should consider both climate change attributed to human activities and natural climate variability (IPCC TAR WG1, 2001, p. 743). Additionally, [...] *a scenario is a coherent, internally consistent, and plausible description of a possible future state of the world* (IPCC TAR WG2 3, 2001, p. 149). Scenarios are commonly required for the assessment of climate change impact, adaptation, and vulnerability in order to give alternative views of future conditions which are considered likely to influence a given system or activity. Climate scenarios, which describe the forcing factor and are the main interest of the IPCC, and the non-climatic scenarios, which gives the socioeconomic and environmental "context" for the climate forcing (IPCC TAR WG2 3, 2001, p. 147).

The IPCC TAR identifies five different types of scenarios:

Socioeconomic scenarios have previously been used to project greenhouse gas emissions, but are now used for assessing climate vulnerability and adaptive capacity. Socioeconomic scenarios can identify various topics, such as population, economic activity, the structure of governance, social values, and patterns of technological change. Thus, these scenarios enable the establishment of a baseline socioeconomic vulnerability before climate change, determine climate change impacts, and also assess vulnerability after adaptation (IPCC TAR WG2 3, 2001, p. 147).

Land-use and land cover scenarios incorporate both land-use and land-cover change scenarios, which are important in the assessment of climate change impact and adaptation. However, they primarily focus on food security and carbon cycling, rather than explicitly addressing climate change issues. These scenarios have been vastly improved since the Second Assessment Report (SAR) to better define current and historical land-use and land-cover patterns, and estimating future scenarios (IPCC TAR WG2 3, 2001, p. 147).

Environmental scenarios encompass future changes in environmental factors, except climate, that will occur regardless of climate change. This includes possible future conditions of marine pollution, water availability, water use, water quality, and atmospheric composition, e.g. carbon dioxide, tropospheric ozone, acidifying compounds, and ultraviolet UV-B radiation, which are all important for modifying the impacts of future climate change. With the exception of CO_2 enrichment, and the effects of this, the rest of the environmental factors have hardly been considered in past assessments of climate changes. However, these factors are being increasingly used with the development of integrated assessments method, which will be explained subsequently (IPCC TAR WG2 3, 2001, p. 147).

Climate scenarios are used for impact assessment. There are three types of climate scenarios: incremental scenarios, analogue scenarios, and climate model-based scenarios. The most common of the climate-model based scenarios use outputs from general circulation models (GMCs), and are typically constructed by adjusting a baseline climate by the absolute or proportional change between the simulated climates of the present and the future. The baseline climate usually based on regional observations of climate over a reference period of e.g. 40 years. Coarse-scale output of GCM's provides regional detail, and this detail is obtained using three different methods: simple interpolation, statistical downscaling, and high-resolution dynamic modelling. The simple interpolation method, which reproduces the GCM pattern of change, is the most commonly used in developing scenarios. The statistical and modelling methods can produce local climate changes, compared to the GCM estimates, which are of a larger scale, however, more research is required to evaluate the value added to impact studies by these methods (IPCC TAR WG2 3, 2001, p. 147).

Sea level rise scenarios are utilised to evaluate threats to humans, ecosystems, and landscape in coastal zones. For impact and adaptation assessment, the most interesting scenarios are the relative sea level scenarios, which encompass sea level rise with reference to movements of the local land surface, as also explained in subchapter 3.2.2.. Base-line levels and trends are established using data on tide gauge and wave height from the last 50 years or more. The most common practise for obtaining scenarios is by applying global mean estimates from simple models, however, by using coupled ocean-atmosphere models, factors of future sea level rise can be modelled regionally. Adding historically observed events onto data on rising mean sea level, can be used to investigate the changes in the occurrence of extreme events, such as storm surges and wave set-up. Some recent studies have begun […] *to express future sea-level rise in probabilistic terms, enabling rising levels to be evaluated in terms of the risk that they will exceed a critical threshold of impact* (IPCC TAR WG2 3, 2001, p. 147). This means that rising sea levels are now being evaluated in terms of the probability that they will reach a certain level, which is considered a critical threshold of impact (IPCC TAR WG2 3, 2001, p. 147).

Scenarios are developed and applied in order to assess future climate change impacts, adaptation and vulnerability, and are thus one of the primary tools for assessing future developments in complex systems that are often unpredictable, insufficiently understood, and have great scientific uncertainties (IPCC TAR WG2 3, 2001, p. 149).

4.2.1.1 The Integrated Assessment Analysis

All of the aforementioned scenarios are applied in an Integrated Assessment Analysis, as shown in figure 12 below. The Integrated Assessment Analysis seeks to give policymakers […] *a coherent synthesis of all aspects of climate change* (IPCC TAR WG2 2, 2001, p. 118). The Integrated Assessment Analysis utilises one or more of four methodological approaches:

(1) Computer-aided modelling […] *in which interrelationships and feedbacks are mathematically represented, sometimes with uncertainties incorporated explicitly* (IPCC TAR WG2 2, 2001, p. 118), (2) Scenario analysis which examines […] *representations of how the future might unfold* (IPCC TAR WG2 2, 2001, p. 118), (3) Simulation gaming and participatory integrated assessment, including policy, and (4) Quantitative assessments, which […] *are based on limited and heterogeneous data and built from existing experience and expertise* (IPCC TAR WG2 2, 2001, p. 118), which can be used as a basis for the research that examines regions and sectors in which uncertain futures makes it unclear where and when impacts might be most severe (IPCC TAR WG2 2, 2001, p. 118).

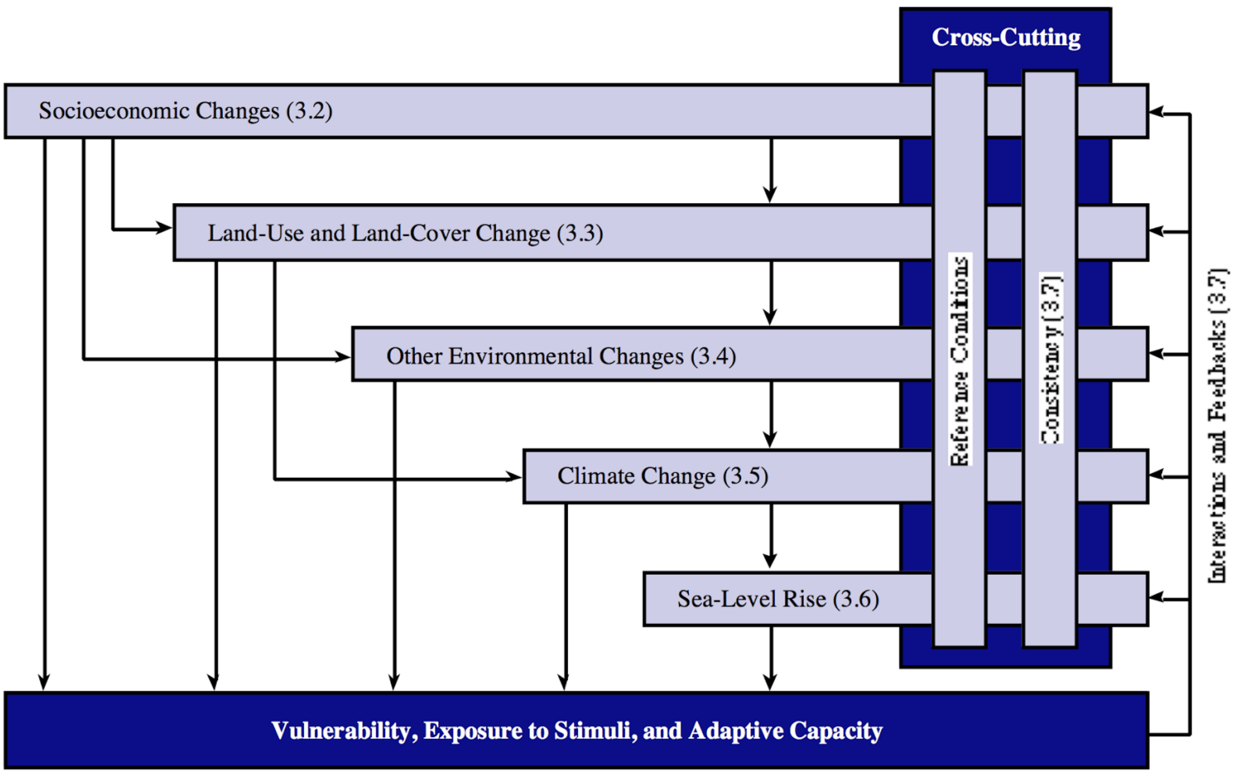


Figure 12: Integrated Assessment Analysis (IPCC TAR WG2 3, 2001, p. 151)

4.2.2. Adaptive capacity

According to both the IPCC and UNEP, when assessing the impact of climate change, the adaptive capacity of a system is a vital component to include, as *plants, animals, and humans will not simply continue on as they have without climate change but are quite likely to modify their behavior* (UNEP, 1998, p. 117). The adaptive capacity of a system is how well the system is capable of or has the potential to […] *respond successfully to climate variability and change* (IPCC AR4 17.3.1, 2007). This includes anthropogenic adjustments not only in the basic conduct of human activity, but also in the way, we utilise resources and develop technologies. In order to develop and implement effective adaptation strategies regarding climate change, the adaptive capacity is a vital component.

Adaptive capacity has both generic and local indicators. Some factors are significant all over the globe, while others are determined by local conditions with specific impacts from climate change. Examples of generic indicators are education, income, and health, whereas indicators specific to a particular impact (e.g. floods) can relate to institutions (e.g. governmental), and the level of knowledge and technology (Yohe and Tol, 2002; Downing, 2003; Brooks *et al.*, 2005; Tol and Yohe, 2007 in IPCC AR4 17.3.1, 2007). As such, the adaptive capacity is influenced not only by the geology and biology of the area, but also the economy, institutions, technology etc.
In this project, the focus lies mainly on government and institutional efforts to enhance the adaptive capacity of the Danish coastlines, including large residential areas. According to the IPCC Assessment Report 5, especially the government has:

> […] *the potential to directly reduce the risk and enhance the adaptive capacity of vulnerable areas and populations by developing and implementing locally appropriate regulations including those related to zoning, storm water management and building codes, and attending to the needs of vulnerable populations through measures such as basic service provision and the promotion of equitable policies and plans*
>
> (Adger *et al*., 2003b; Brooks *et al*., 2005; Nelson *et al*., 2007; Agrawal and Perrin, 2008; Agrawal, 2010 in Noble *et al.*, 2014, p. 842).

Put differently, the government is *the* vital actor when it comes to making sure that both the physical environment and the people living in it are not exposed to hazards deriving from changes to the climate.

However, within all societies, there are individuals/groups/municipalities/regions […] *that have insufficient capacity to adapt to climate change* (Noble *et al.*, 2014, p. 839) and additionally, having a high capacity to adapt does not unescapably lead into actions to reduce vulnerability and vice versa (Noble *et al.*, 2014, pp. 839; 854). The current understanding of adaptive capacity is, to a large extent, derived from the assessment of vulnerability. The indicators of vulnerability […] *often provide important insights on the factors, processes and structures that promote or constrain adaptive capacity* (Eriksen and Kelly, 2007 in IPCC AR4 17.3.1).

4.2.3. Vulnerability

Vulnerability to climate change is the extent of how exposed, or unable to cope, geophysical, biological and socio-economic systems are, when it comes to the negative impacts of climate change. When utilising the term vulnerability, it can refer to either the vulnerability of the system itself (e.g. flooding of coastal areas) or the mechanisms causing these impacts (e.g. the collapse and disintegration of ice sheets in the arctic) (IPCC AR4 19.1.2.1, 2007). Initially, vulnerability was defined as a function of:

1) Exposure to specific hazards or stressors
2) Sensitive to their impacts, and
3) The target population's capacity to adapt

(IPCC AR3 (TAR), chapter 17 in Noble *et al.*, 2014, p. 854)

Recently, however, the focus has moved from […] *defining exposure and potential impacts to a better understanding of the factors that affect societies' sensitivity to those impacts* (Noble *et al.*, 2014, p. 854) and their adaptive capacity. As such, the social vulnerability has become increasingly recognised as an important factor to include alongside the biophysical vulnerability (Noble *et al.*, 2014, p. 854).

Nonetheless, the term vulnerability is still under discussion, as the term is not well defined. Thus the amount indicators of vulnerability are vast and the purpose of these indicators varies, whether they are to produce a vulnerability rating or […] *to identify adaptation options* (Smit and Wandel, 2006; Sietz *et al.*, 2011b in Noble *et al.*, 2014, p. 854).

Indexes of vulnerability can be derived both deductively by identifying indicators that, in theory, […] *should be strongly related to vulnerability* (Noble *et al.*, 2014, p. 854) or inductively, through observed data, seeking […] *correlations between indicators and observed consequences of vulnerability, such as the number of people killed or affected by climate related events in recent history* (Noble *et al.*, 2014, p. 854).

4.2.4. IPCC's notion of risk

The IPCC released a special report regarding disaster risk management and climate change adaptation (IPCC, 2012) where it addresses the concept of disaster risk. Lavell *et al.* (2012) in the special report by the IPCC, defines disaster risk as:

> [...] *the likelihood over a specified time period of severe alterations in the normal functioning of a community or society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery*
>
> (Lavell *et al.*, 2012, p. 32).

The interactions between the relevant concepts to disaster risk can be seen in figure 13.

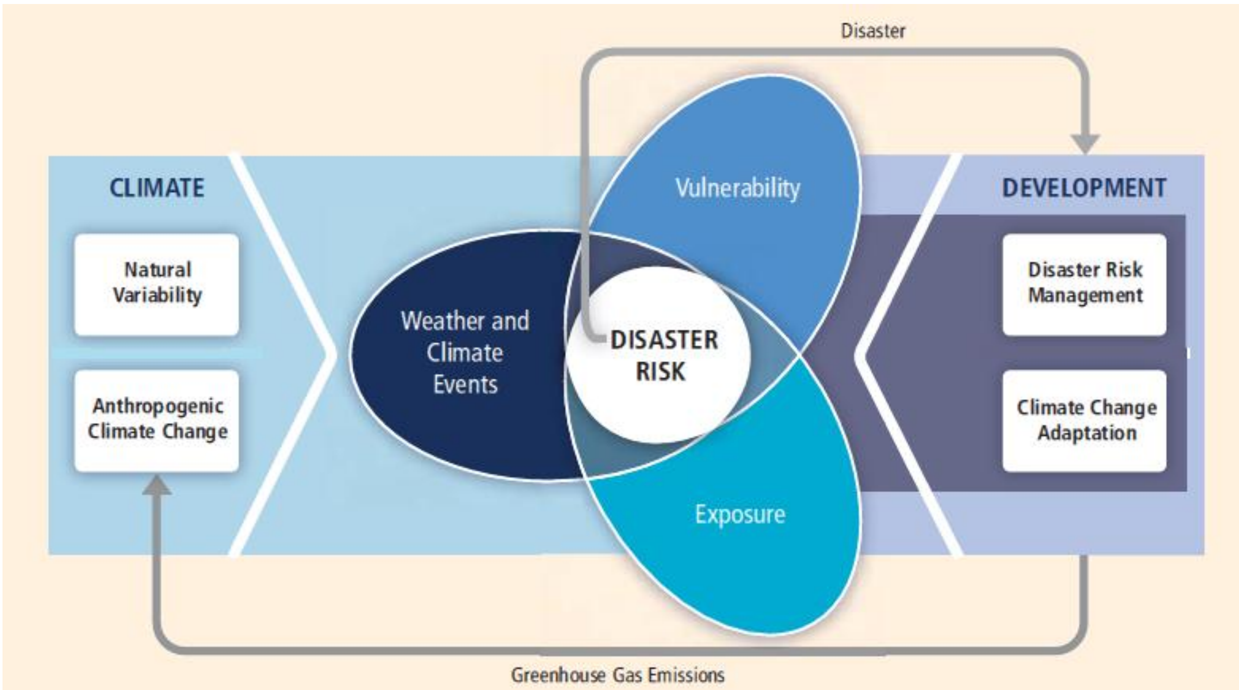


Figure 13: IPCC's concept of disaster risk (Lavell *et al.* 2012, p. 31).

Figure 13 shows the complexity of the IPCC notion of risk. Here, we see the central concept, disaster risk, being an integrated combination of: weather and climate events, vulnerability and exposure. Weather and climate events are affected directly by the climate in general, which encompasses the natural variability of climate and the impacts of anthropogenic induced climate change. Oppositely, vulnerability and exposure of communities are affected by the processes of development, which includes the disaster risk management and climate change adaptation. In turn, disaster risk impacts development, as the presence of a risk will emphasise the demand and urgency for such. Finally, development will affect the climate through greenhouse gas emissions, as disaster risk management and adaptation often is associated with energy consumption.

It can be observed that mitigation is not included in figure 13. This can be justified considering that the main focus of mitigation concerns reducing the utilisation of fossil fuels, however a combined model could show even more aspects to the concept of disaster risk.

An example of an area, which has increased its vulnerability to future climate change, is the Bay of Køge, where properties have been built on known hazard zones for flooding. The risk of flooding comes from several sources, one of which is the sea. The more inhabited areas of the Bay of Køge are situated close to the waterfront. This increases the risk of cities and other inhabited areas being affected by flooding. Additionally, the water table is very high due to shallow layers of lime, and there is a small slope from inland towards the sea, leading rainwater towards the inhabited area. The rainwater is stopped by the road (Køge Bugt Motorvejen) which functions as a barrier for both water from the ocean, and stops water from inland. Both sides (but mostly the side towards the sea) of the highway have a high population density.

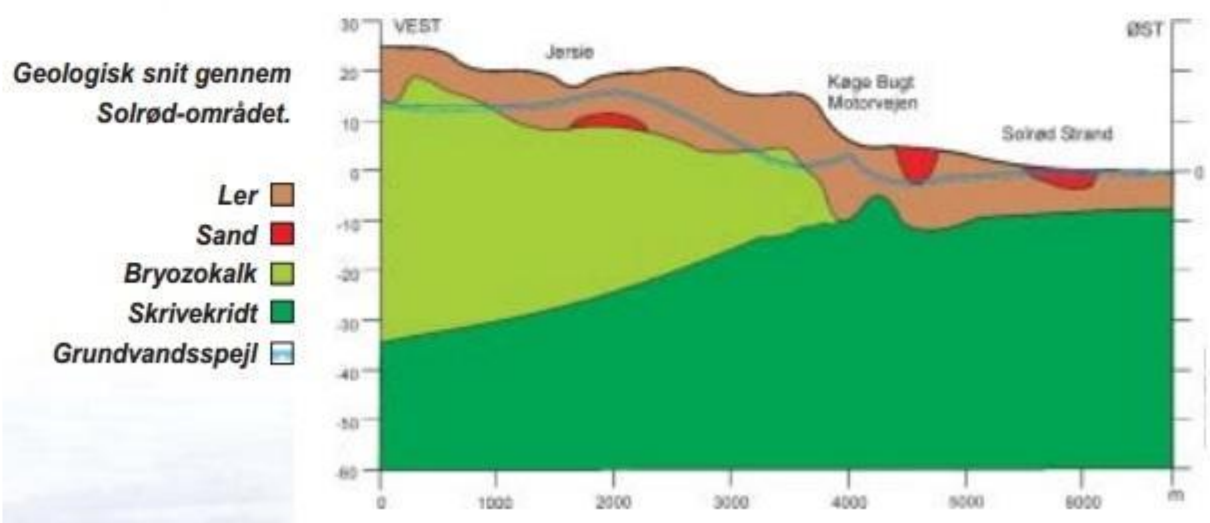


Figure 14: Illustration of Solrød's geological characteristics (Roskilde County, 2005, p. 10)

4.3. Conclusion to working question 1

How do the EU Floods Directive and the IPCC propose to approach climate change, specifically in relation to flooding and sea level rise?

The EU Floods Directive from 2007 instructs its 27 (as of 2007) Member States a three step game plan; (1) Preliminary Risk Assessment and selecting risk areas (deadline 2011), (2) Flood Hazard Mapping and Flood Risk Mapping of selected areas (deadline 2013), and (3) the creation of Flood Risk Management Plans, based on the flood maps (deadline 2015).

The concept of flood risk is defined as the potential adverse consequences (which is the value of the factors at risk × the damaging effect × the exposure of the factors at risk) × the probability of a flood event. Arguably, the EU Floods Directive approaches climate change and associated sea level rise using semi-empirical models, where historical context plays a significant role in the production of evidence, and their concept of flood risk is based primarily on these past storm surge events.

The IPCC utilises a range of climate change scenarios in order to make estimations of the future climate, including flooding and sea level rise. The five categories for climate change scenarios are; socioeconomic, land-use and land cover, environmental, climate, and sea level rise scenarios. These five categories are all included in the Integrated Assessment Analysis, which was created to include all aspects of climate change, making it more accessible for policy makers to understand the full extent of the predicament. The end-results of the scenarios are estimations of the vulnerability and adaptive capacity of the area in question. The adaptive capacity is defined as how well a system can respond to changes in the climate, whereas vulnerability encompasses both the social and biophysical aspects of exposure and sensitivity of an impact as well as the adaptive capacity. Lastly, the IPCC has created a complex definition of the term disaster risk, which in a simplified version is the sum of the vulnerability, weather and climate events, and the exposure. However, each element is in turn affected by other events, and as such, the IPCC makes use of cause-effect pathways as studied in the Causal Chain Analysis. This corresponds well with process models, which are associated with much more complexity.

5. Working question 2: Comparative Analysis

This chapter will make use of a comparative analysis (as explained in chapter 2) in order to answer working question 2: *What are the main differences between the two methodologies and how can they be exemplified through the selected method-illustrations?*

The frame of reference for this comparative analysis is based on the issue of projected flooding attributed to climate change and the related choice of methodologies when dealing with this. The comparable institutions are: 1) The EU Floods Directive and, by extension, the Danish government, and 2) the IPCC. The EU Floods Directive and the Danish government use methodologies in the assigning of projected risk areas, which are predominantly different from the methodologies used by the IPCC. Furthermore, the choice of methodology by the Danish government is questioned in this comparison, as they failed to select the Municipalities of Roskilde and Frederikssund as high risk flood areas - when these locations were later subject to severe flooding due to storm surge. The question is whether the choice of methodology by the IPCC is more appropriate when selecting high risk flood areas, which lays as grounds for comparison in this analysis. The organisational scheme of this analysis will use a point-by-point structure, where the two institutions engage in a debate throughout the chapter. The comparison will, as such, discuss different themes with comparable arguments from both of the cases. We will use this comparative analysis in order to assess our thesis and problem formulation, which will be merged in the final conclusion.

The methodological approach of Projection Analysis, utilised by the EU in their Floods Directive, relies heavily on data on historical climate events, dating back to as late as the 16th century (The Danish Coastal Authority, 2011b, p. 3), in the assessment of flood risk. Risk is defined as the potential adverse effects of a flooding event and the probability of a flood event, as mentioned in chapter 4.1.1..

The methodological approach of the Causal Chain Analysis, utilised by the IPCC in their Assessment Reports, use data on recent events, dating back 50 years or less (IPCC TAR WG2 3, 2001, p. 147), in addition to several other considerations, which impact the assessment of the flood risk and the vulnerability of a flood risk area, such as considerations about socioeconomic-, land use and land cover-, environmental-, climate-, sea level rise circumstances, see chapter 4.2.1.. The IPCC defines vulnerability as exposure to specific hazards or stressors, sensitivity to their impacts, and the target population's capacity to adapt, as mentioned in chapter 4.2.3..

The use of projections and models and the use of the concepts of risk and vulnerability utilised by the EU and the IPCC will be comparatively analysed in more detail in the following subchapters 5.2., and 5.3., respectively.

5.1. Use of projections and models

This subchapter will discuss the use of projections and models in dealing with future sea level rise attributed to climate change, firstly according to the EU Floods Directive and its implementation in a Danish context, and secondly in relation to the IPCC. This subchapter will preliminarily conclude on the key aspects to each of the approaches in relation to modelling.

The EU Floods Directive makes projections for the potential future flood risk through the production of Flood Hazard Maps and Flood Risk Maps (see chapter 4.1.1.). The EU Floods Directives suggests that the mapping can be based on 1) Databases, and 2) Flood modelling (EXCIMAP, 2007, pp. 33-34).

The databases include information on topography received through digital elevation models (DEM), where a minimum 0.5 m vertical resolution is required. Databases also utilise historical data, which are deemed [...] *very important for public awareness rising as well as for the calibration of flood modelling (as long as past and modelling conditions can be compared)* (EXCIMAP, 2007, p. 33) and can be based on a variety of historical records of flooding, such as records, articles, pictures and even paintings. Finally, land use and related data is based on population and economic data, cultural heritage, aggregated land and services, environment, and infrastructure. The EU Floods Directive finally suggests four types of flood modelling when making Flood Hazard Maps and Flood Risk Maps: (1) hydrological models, (2) hydraulic models, (3) large floodplain areas, and (4) coastal flooding (EXCIMAP, 2007, p. 33-34).

In this context, the Danish Coastal Authority bases its flood projection on past storm surge and flooding events dating back to the year 1532 (The Danish Coastal Authority, 2011b, p. 3). In evaluating the relevance of a flood event, five categories have been used to specify the event: water level, meteorology, flooding, damage, and anthropogenic consequences (The Danish Coastal Authority, 2011a, p. 23; 25; The Danish Coastal Authority, 2011b). The Danish Coastal Authority uses these past storm surge events as a baseline year 2010 scenario. This baseline year 2010 scenario is used in comparison with a year 2060 scenario, where a 0.3 metre sea level rise has been perturbed onto the baseline values (The Danish Coastal Authority, 2011b, pp. 60-62). The Danish Coastal Authority uses 0.3 metre sea level rise as a general estimate of future sea level rise during a period of 50 year (4.1.2.). There are no apparent explanations for how the 0.3 metre future sea level rise was determined, and there seems to be some dispute to this assessment, as the Risk Management Plan from the Municipality of Solrød from December 2014 includes an expected general sea level rise of 0.5 metre (Municipality of Solrød, 2014b, p. 5).
The Danish Coastal Authority uses a combination of two models: (1) the Danish elevation model (DHM), and (2) the sea flood model. The Danish elevation model is used in assessment of the altitude of terrain. The potential for flood is determined by:

> *a) the past maximum water level in a given geographical region,*
> *b) a professional evaluation of the hydrodynamic conditions in the region, and*
> *c) a projected climate-induced factor for sea level rise*
> (The Danish Coastal Authority, 2011a, p. 63 - own translation from Danish)

The models thus use the expected 0.3 m sea level rise for 2060 as perturbed onto the historical storm surge data in order to project future flooding. This methodology assumes that the terrain does not change (see chapter 4.1.2.).

The IPCC conducts projections through models based on a variety of scenarios with a critical stance on the use of baselines. The IPCC finds that baselines change even without climate change due to the [...] *ongoing socioeconomic development and, with climate change, because of system responses and autonomous adaptation* (IPCC TAR WG2 2, 2001, p. 115). Based on future changes in anthropogenic greenhouse gas emissions, the IPCC then suggests a range of plausible projection scenarios (see chapter 4.2.1.).

The IPCC uses a variety of different models when they attempt to make projections about these future scenarios. The Atmosphere-Ocean General Circulation Models were previously considered the "standard" model and has been the primary function to [...] *understand the dynamics of the physical components of the climate system (atmosphere, ocean, land and sea ice), and for making projections based on future greenhouse gas (GHG) and aerosol forcing* (Flato *et al.*, 2013, p. 746). The Earth Systems Models then expand on the Atmosphere-Ocean General Circulation Models through terrestrial processes, and the Regional Climate Models are thus used to in order to downscale global models to a smaller scale of region (Flato *et al.*, 2013, p. 746-747). These models attempt to simplify real systems and their processes through mathematical terms and extensive technological computation (Flato *et al.*, 2013, p. 749).

In summary, the EU Floods Directive and the Danish Coastal Authority use historical events dating back to the 16th century for a year 2010 baseline. This baseline is used in comparison to a single projected year 2060 scenario, where they perturb an estimated factor of predicted sea level rise (0.3 metre) onto the baseline. The use of models is as such semi-empirical (as described in chapter 3.3) and fairly simple due to the simplicity of the equation, and the computational demand is relatively small.

Oppositely, the IPCC is critical of the use of a baseline, due to the changing dynamics of natural and socioeconomic systems. The IPCC's use of several scenarios based on change in anthropogenic behaviour stands in contrast to the Danish Coastal Authority's single scenario. Finally, the IPCC makes use of complex global models, as well as complicated downscaling methods, and can thus be defined as process models (see chapter 3.3). The inputs and processes of these can be difficult to understand and can lack transparency due to the complexity and quantity of facts involved. Alternatively, the EU Floods Directive lacks the incorporation of the complexity of systems in their models. The EU Floods Directive thus runs the risk of underestimating flood risk due to an inflexible use of projections, as these are grounded primarily in past events.

5.2. Risk and vulnerability

This subchapter will analyse the concepts of risk and vulnerability, firstly in the context of the EU Floods Directive, followed by their use in a Danish context. Secondly, this subchapter consider the way the IPCC uses risk and vulnerability, and the two different approaches will lastly be summarised in contrast to one another.

As elaborated in the previous part of the project, the assessment of vulnerability is utilised by both the EU Floods Directive and the IPCC, and is considered as […] *a key concept for understanding the impacts of climate change and natural hazards* (Masselink & Gehrels, 2014, p. 106). But the definition of the term vulnerability differs, as some regard vulnerability as an equivalent to the term risk. An example of this can be found in Masselink & Gehrels (2014):

> *The vulnerability of a coastal community can be regarded as the sum of risks to its social, economic and physiographic properties, and is inversely related to the natural and social coping and adaptive capacity to adverse impacts, i.e. a society's resilience*
>
> (Masselink & Gehrels, 2014, p. 106).

As such, vulnerability is defined as a combination of economic, social and geo-ecological *risk* (Masselink & Gehrels, 2014, p. 108). A similar definition of vulnerability is found in the EU Floods Directive, as mentioned in the previous chapter regarding working question 1. Here the risk of a flood is defined as the potential adverse consequences (vulnerability) × the probability of a flood event. The potential adverse consequences are subsequently defined as value × effect × exposure, thus defining vulnerability as a function of value, effect and exposure.

In a Danish context, the risk of flood is also defined as a function of a) the probability of a flood event and b) the potential adverse consequences (Danish Coastal Authority, 2011a, p. 13).

a) The potential adverse consequences are in this context dealt with through a Vulnerability Assessment. These assessments are divided in three groups, depending on the scale of the assessment:

1) Makro-based analysis, which are designed to be the supporting basis for the implementation of national legislation regarding a reduction in flood risk.

2) Meso-based analysis, which are meant to support the makro-based strategies for the country, by implementing the strategy in a given region.

3) Micro-based analysis, which is intended to support local decisions regarding concrete adaptation measures toward the risk of flood.

The more detailed Vulnerability Assessment, the more expensive it is to carry out. As such, detailed Vulnerability Assessments are only made on the micro-basis, whereas regional and national analyses have a lower level of accuracy for vulnerability (Danish Coastal Authority, 2011a, pp. 15-16).

b) The probability of a flood is found through a Hazard Analysis. The Hazard Analysis examines all registered events with extreme levels of water at a given location. On a basis of the empirical data, the probability of a certain water level can be calculated. The probability of an extreme level of water is listed as a return period (in Danish: middeltidshændelse), that is the estimated likelihood of how often a certain water level can occur or be surpassed in a given time frame (e.g. every 10, 100 or 1000 years) (Danish Coastal Authority, 2011a, p. 13).

This differs from the way the IPCC deals with the terms of vulnerability and risk. As aforementioned regarding the two ways of making projections of climate change, the models, projections and also terminology of the IPCC is more complex and includes more valuables in their classifications. As elaborated in the previous chapter, the IPCC defines vulnerability as a function of exposure, impact sensitivity and the adaptive capacity of the system. Thus, both the social and the biophysical vulnerability are included as the components of vulnerability.

The definition of risk (more specifically *disaster* risk) by the IPCC is a combination of weather and climate events, vulnerability and exposure, where the effects of events extents to human, material, economic and environmental spheres. At first this seems very similar to that of the EU Floods Directive, however the IPCC expands their definition by including how each of the three components of risk are additionally affected by other components (e.g. how exposure is related to the development of climate change adaptation).

In this regard, the biggest difference between the EU Floods Directive and the IPCC is the fact that the EU Floods Directive includes the probability of a flood event – a probability based on previous events. The method is simple and easy to use, but it makes the reservation that what happened in the past, will also happen in the future (+ 0.3 metre). However, climate change *changes the climate* and the associated impacts become evident at new locations and at a different rate than before. The IPCC however, is very complex and, as the GIWA Causal Chain Analysis points out, can potentially become difficult to investigate. It is therefore important to select the most relevant variables to be analysed, instead of included all of them – keeping in mind the removal of a variable needs to be judicious.

5.3. Conclusion to working question 2

What are the main differences between the two methodologies and how can they be exemplified through the selected method-illustrations?

The consequence of utilising the methodological approach of the Projections Analysis, as suggested by the EU in the Floods Directive, with the use of historical events and digital elevation models for the identification of flood risk areas, is that this method only projects areas of risk, where there has been hazardous events before. As such, utilising the Projection Analysis could result in the disregarding of areas, which could potentially be at risk, on the grounds that the area in question not previously have been flooded or due to special geological circumstances, which were not considered. The use of these semi-empirical models assumes that terrain does not change; however, it is inevitable that terrain will change with and without the attribution of climate change.

The Danish government utilises a methodological approach inspired by the Projection Analyses of the EU in their assessment and identification of possible risk areas. Upon being assigned the task of identifying the potential flood risk areas of Denmark, 10 areas were identified, as mentioned in chapter 1.4. Roskilde Fjord and the Municipality of Frederikssund were not identified as flood risk areas. However, both were severely flooded during a storm surge in December 2013, see chapter 1.4. This illustrates a potential disadvantage of utilising the method of the Projection Analysis.

Another potential disadvantage of utilising the method of Projection Analysis could be that the method is at risk of underestimating the future problem, due to the inflexibility of the method in regards to insufficient consideration of the effects attributed to climate change with the perturbed 0.3 metre, which is the commonly accepted, projected, future sea level rise in the EU. Adaptation and mitigation projects, which only allow for an additional 0.3 metre increase, could be deemed inadequate, if the projections turn out to be inaccurate. As a result, the capital invested in the projects will be wasted. Additionally, the targeted people of the flood risk area would rely on a false sense of security because of the inadequate projects.

Utilising the methodological approach of the Causal Chain Analysis, as used by the IPCC in its Assessment Reports, could also have potential disadvantages. The many cause-effect pathways considered by the methodology increase the risk of miscalculation, due to the mathematical calculations becoming too long for the models to calculate adequately. Since the understanding of the complex system of the climate, and the mathematical representations of the climate system, is still limited (IPCC AR5, 2014), one small miscalculation could potentially have an exponential effect on the result.

Contrary to the Projection Analysis, upon utilising the methodology of the IPCC in the assessment of future sea level rise, there is a risk of overestimating the future problems. If the future sea level rise is overestimated, the cost of projects for climate change adaptation will increase. This could result in projects being rejected due to the increased cost.

However, both methods do contribute to climate adaptation. The Projection Analysis offers a method with simplicity and transparency, making it straightforward and relatively easy to use. Thus, it can be beneficial for especially policy makers to engage in, as the transparency of the method allows for an increased ease of implementation. Oppositely, the Causal Chain Analysis contributes to climate adaptation in the way that it incorporates a large range of factors, which exemplifies the components in a complicated system well. This is apparent in the IPCC's use of high-demand computational modelling, well aligned with theory behind process models. The complexity in the cause-effect pathways associated with the Causal Chain Analysis allows for a more in-depth examination of what impacts to avoid and how to avoid them. Taking into account societal factors and concepts of vulnerability and adaptive capacity, the Causal Chain Analysis will arguably be more likely to not underestimate future adverse consequences in sea level rise attributed to climate change.

The two different method illustrations, the Projection Analysis and the Causal Chain Analysis, are thus used to exemplify the actual methodologies used respectively by the EU and the IPCC. These two approach consequently each find their beneficial purposes in their weaknesses: The Projection Analysis used by the EU Floods Directive may be too simple to effectively project future conditions and can thus underestimate potential impacts of climate change. However, the simplicity of it makes it more transparent and straightforward to use by policy makers. The Causal Chain Analysis used by the IPCC includes a lot of complicated modelling and tracking errors can as such be difficult. Contrary to the Projection Analysis, this method does not offer a lot of transparency. However, the usage of these complex factors is associated with more security in future projections due to its tendency to not underestimate future conditions.

6. Final conclusion

This chapter will address the problem formulation: *How can the methodologies of, respectively, the EU Floods Directive and the IPCC be compared, using two different prototypes of approaches regarding sea level rise attributed to climate change, in a Danish context?* Additionally, the conclusion will culminate in an assessment of to which extend the two methodologies can be considered a relevant tool to achieve successful adaptation.

The prototype of the Projection Analysis bases its projection for the future on past events, thus projecting the likelihood and extent of future flooding events in areas, which have experiences such events before. The EU Floods Directive includes this in the utilised methodology of risk assessment, additionally including the value and exposure of the factors at risk, and the effect the event might have on the area.

The methodological approach of the IPCC encompasses recent historical events in combination with considerations of socio-economic scenarios, land-use and land cover scenarios, environmental scenarios, climate scenarios, and sea level rise scenarios, in an integrated assessment analysis. Computing models use this information and data to calculate the vulnerability, exposure to stimuli, and adaptive capacity of a given location, in order to evaluate the flood risk of set area. The methodological approach of the IPCC is based on a Causal Chain Analysis, which analyses the cause-effect pathways between all the different factors considered, thus giving a complete and coherent picture.

Both methodologies utilise projections, however the EU Floods Directive makes use of empirical data going back, in the Danish context, to the 16th century, whereas the IPCC only goes back approximately 50 years. Additionally, the IPCC has a large range of different scenarios all including different factors. Regarding baselines for comparison, the EU Floods Directive has the presupposition that the terrain in question does not change, while the IPCC maintains that terrains do change and that baselines as such must be addressed critically. In this context, the matter of understating the problem becomes an issue with the EU Floods Directive, as the stand on baseline results in the possible oversight of new areas in risk of flooding. Oppositely, as the IPCC includes such a large range of factors, the possibility of overstating the problem is likely.

The methodology of the EU Floods Directive is simple, easy to use and the mechanisms are transparent, thus making the implementation easy for policy makers to execute. The methodology of the IPCC is complex and thus lacks transparency, but it includes more factors and cause-effect pathways, resulting in a higher authenticity (while recognising the risk of miscalculation).

Ultimately, the EU imposes its Directives upon Member States, but it is to the respective national authorities to decide on the methodology they use. Evidently, the Danish government opted to use the methodology proposed by the EU Floods Directive, even though they had the option to select a different methodology. 10 flood risk areas were identified throughout Denmark based on past flood surge events dating back to 1532. The Bay of Køge was among the selected areas, because of its low altitude and its several incidents of past flooding. Thus, it is expected that the Bay will be flooded in the future. However, areas surrounding Roskilde Fjord were overlooked in the process. The storm 'Bodil' and the associated storm surge that flooded large areas in the Municipalities of Roskilde and Frederikssund proves that the methodology applied by the EU Floods Directive and the Danish government is faulty. Arguably, there is a need for measuring the success of adaptation and how society deals with future challenges attributed to climate change.

Adaptive capacity and robustness are key concepts in determining the success of adaptation. Criteria for robustness such as reversibility, reducing vulnerability and no regrets aim for a more flexible methodology, which can be adjusted temporally and spatially to better suit the place of interest. Robust and flexible adaptive measures are well aligned with the recommendations by the IPCC, where attempts to reduce vulnerability by increasing the adaptive capacity is the focal point. The Causal Chain Analysis is used to first state undesirable impacts to a given location and then tracks the associated causes through intricate cause-effect pathways. Assessments thereof can then be used to determine how vulnerability against such can be reduced. Reducing vulnerability can be easily alterable in case adjustments are required due to flaws in future projections. Alternatively, the methodology of the Projection Analysis, where a historical context is utilised in order to argue for future adaptive procedures, cannot be considered nearly as robust or flexible as it is primarily concerned with where past flood surge events have occurred, and not where they could occur under future conditions, geophysically and socioeconomically. Thus, according to the Projection Analysis, a given location needs to become flooded before it can be included in the probability of future flood risk areas. The Projection Analysis does, however, contain one of the criteria for robust adaptation in its transparency and ease of implementation for policy makers. This criteria turns out to be essential, as the EU in its Floods Directive arguably were required to develop a scheme simple enough so that it was manageable by all its Member States. However, the methodology used by the EU Floods Directive and, by extension, the Danish government only meets one of the requirements for robustness and it can therefore not be considered a competent tool in achieving successful adaptation. Thus, the IPCC fulfils more of the given criteria for a successful adaptation.

7. Literature

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