Usable sea level rise information for Dutch coastal cities

Explaining the factors that influence the usability gaps within coastal climate services regarding sea level rise information

Laurens-Jan de Rijk

Master's thesis

Radboud University

April 2023

Usable sea level rise information for Dutch coastal cities

Explaining the factors that influence the usability gaps within coastal climate services regarding sea level rise information

Colophon

Document:	Master's thesis
Study:	Spatial Planning
Specialization:	Cities, Water & Climate Change
Date of submission:	20-4-2023
Author:	Laurens-Jan de Rijk
Student number:	s1010999
Organization:	Radboud University, Nijmegen
Faculty:	Nijmegen School of Management
Internship:	Deltares
Supervisor Radboud University:	Prof. Dr. S.V. Meijerink (Sander)
Supervisor Deltares:	G.J. Koers MSc (Gerben)

Cover image:

USGS/ESA (2011). *Rotterdam and surrounding Rhine-Meuse-Scheldt delta – captured by Landsat-5 in 2006.* Retrieved from: ESA - Rotterdam, Netherlands

Preface

Before you lies my master's thesis about the usability gaps within coastal climate services regarding sea level rise information used in Dutch coastal cities. This is the end-product of the Spatial Planning program at the Radboud University in Nijmegen. Besides that, it is a part of my internship at Deltares, which is an independent institute for applied research in the field of water and subsurface. During my study, it became clear that I am very passionate about the complexity of climate change and its relation to the water sector. This interest started a little earlier, as I did my bachelor thesis about flood risk reduction in relation to land use planning in the Netherlands. In addition, I have done smaller research projects as well in which issues like sea level rise, flood risks, periods of drought or heavy rainfall were discussed in related to its governance-structure. However, the subject of my master's thesis is slightly different, which has given me a chance to walk an alternative path.

My thesis focuses on the usability gaps within coastal climate service regarding sea level rise information that are used in Dutch coastal cities. Sea level rise is considered to be a major threat for coastal cities, as it is linked to a higher chance of flooding, salinization, beach erosion or changes in wetlands and marshes. Stakeholders responsible for developing adaptation strategies towards sea level rise need coastal climate services such as maps, graphs or scenarios in order make well-informed decisions. However, end-users of these services are not using or are not capable of using these services during adaptation processes, resulting in various usability gaps. By providing information on the factors that influence these usability gaps, I have not only broadened my knowledge about the theme of sea level rise, but also contributed insights for the development of usable coastal climate services.

To conclude, I would like to say a few words of thanks, starting with my thesis supervisor Sander Meijerink from the Radboud University. You have provided me feedback and reflected on my work critically during the whole process, which helped me a lot. Besides that, I would like to thank my supervisor from my internship at Deltares, to which I could ask anything at all times, which has been of great help to me. Your insights have been very valuable. As my thesis is also part of the Coastal Climate Core Project (CoCliCo), I also would like to thank Arjen Luijendijk for providing me the opportunity to work in a real-life project. In addition, I would like to thank all respondents who have participated within this research. Without their knowledge and insights, it would not have been possible to conduct this research. Lastly, I would like to thank my family and friends for supporting me during this process.

For now, I hope you will enjoy reading my thesis as much as I enjoyed writing it.

Yours sincerely,

Laurens-Jan de Rijk
April, 2023

Abstract

When it comes to sea level rise (SLR), it is important to provide timely and tailored information that could be used during adaptation processes. SLR, a climate related issue, is complex and its impact differ per region of the world. Throughout many years, scientists have tried to translate climate science into climate services (CS), which can be defined as 'information services that provide information about climate change, climate impacts and climate adaptation strategies for decision-makers and other stakeholders to create understanding, to raise awareness, and to make decisions'. By doing so, complex information would be more understandable and usable for decision-makers that are responsible for climate adaptation.

Considering the Netherlands, SLR can be seen as one of the main climate issues to adapt to. It is posing a major threat for the Dutch coastal cities as its consequences could lead to economic, social and environmental damage and disruption. In order to find ways to adapt to SLR, there is a need for scientific information that is suitable for responsible Dutch decision-takers. SLR information is often translated into coastal climate services (CCS), which are used by responsible stakeholders in coastal areas. However, it is stated that CCS are often not being used during the adaptation process. A mismatch between the information provided by climate scientists and the end-users of the service can be observed, leading to various usability gaps. Within literature, it was noted that these usability gaps could be influenced by four factors: stakeholder, purpose, information and visual format. These factors can in turn be expressed in relative levels of validity, readability and interactivity. Therefore, this research focuses on the factors that influence the usability gaps within CCS regarding SLR information. To be able to do so, the following main question has been needs to be answered:

''Which factors explain the usability gaps in coastal climate services regarding sea level rise information for Dutch coastal cities?''

To provide an answer to this question, qualitative research has been conducted. A comparative case study has been done, in which the factors that influence the usability gaps within the CCS used in the coastal cities Rotterdam and Vlissingen are being discussed. First of all, desk research has been done to understand which CCS are available and to what extent CCS are being used. Secondly, semi-structured interviews have been done with multiple stakeholders that have a particular responsibility towards SLR adaptation. These participants have been asked which CCS are used, what their SLR information needs are during the adaptation process and eventually what factors influence the usability gaps within the used CCS.

From this research, it can be concluded that various usability gaps exist. The factor that was mentioned the most was information validity, referring to the level of uncertainty of the SLR scenarios provided by the KNMI scenarios. Also, the categories of purpose validity and stakeholder readability were mentioned often. However, there was a clear difference within the interviewed institutes. The water boards and the regional departments of Rijkswaterstaat within both cases did not mention many usability gaps within the CCS they make use of, only some slight gaps regarding the uncertainties of SLR scenarios. Other stakeholders (including province of Zeeland, the municipality of Rotterdam, the municipality of Vlissingen and the Port of Rotterdam) stated usability gaps like a lack of detailed information, a lack of reliable information, a lack of simplified information for raising awareness or a lack of information attuned for local decision-making.

Keywords: *Climate information*; *(coastal) climate service; climate change; sea level rise; adaptation processes; usability gap;*

List of acronyms

Acronyms

CS:	Climate service
CCS:	Coastal Climate Service
CoCliCo:	Coastal Climate Core Services
HD:	Hollandse Delta
ISO:	International Organization for Standardization
KasZ:	Klimaatadaptatiestrategie Zeeland
NAP:	Normaal Amsterdams Peil / Normal Amsterdam Level
RWS:	Rijkswaterstaat
RWS WNZ:	Rijkswaterstaat West-Nederland Zuid
RWS ZD:	Rijkswaterstaat Zee en Delta
SDS:	Scheldestromen
SLR:	Sea level rise

List of figures and tables

Figures

Tables

Table of contents

1. Introduction

1.1 Climate services and urban adaptation processes

''What is society's relationship to science and how does this relationship shape the science that is produced? How does science move from production to use in decision making?'' (Kirchhoff, Lemos & Dessai, 2013, p.394)''. These questions are more important than ever right now, as it is increasingly recognized that linking scientific knowledge to decision making processes is urgent in order to respond to a world that is rapidly changing due to the impacts of climate change (Cash & Belloy, 2020). Consequences of climate change, such as flooding, heat stress, heavy rainfall or periods of drought, will most likely happen more often in the future and with a higher intensity (Cortekar et al., 2016). Because of this, spatial planning will play a vital role in adapting to climate change, especially when it comes to urban areas (Wamsler, Brink & Rivera, 2013). ''Cities are home for more than half of the world's population and contain most of societies' assets and economic activities, making them highly vulnerable for climate change impacts'' (Cortekar et al., 2016, p.43). In order to build a capacity to withstand future shocks and stresses, developing adaptation strategies is necessary (Leichenko, 2011).

However, climate related issues are often complex and uncertain, which could lead to various problems when creating adaptation strategies (Moser & Ekstrom, 2010). For instance, consequences of climate change vary per region, meaning that it could be difficult to create suitable adaptation strategies on a local level (Cortekar et al., 2016). Therefore, stakeholders responsible for adaptation processes are in need of tools, products, data and services that can help with the understanding of and the adaptation to climate related issues in specific geographical areas (Cortekar, Themessl & Lamich, 2020; Lemos, Kirchhoff & Ramprasad, 2012). Within the last couple of decades, a lot of information about climate change has been made available by climate scientists (Lemos, Ramprasad & Kirchhoff, 2012). Climate information is often translated into so called climate services (e.g., maps, graphs, scenarios, reports or tables), which provide information about climate change, climate impacts and/or climate adaptation strategies (Lawrence et al., 2021; Raaphorst et al., 2020). According to Raaphorst et al. (2020), climate services (CS) are used in adaptation processes to communicate climate data to professionals and other stakeholders in order to facilitate well-informed climate adaptive decision-making. CS offer the opportunity to inform and communicate about climate change impacts, adaptation processes, risk management and realizing resilience against climate change impacts (Street et al., 2015). This also implies that a cross-scale interaction between climate scientists and decision-makers is crucial, meaning that the provided information within the CS should be tailored to the information needs of the end-user (Cash & Belloy, 2020).

1.2 Coastal climate services for sea level rise adaptation in (Dutch) coastal cities

Existing CS focus on different thematic areas that vary by country and region. For instance, global and national frameworks for CS have been created to provide support to adaptation activities towards issues like heat stress or periods of drought (Le Cozannet et al., 2017). However, less information is made available to support coastal adaptation (Le Cozannet et al., 2017). This may be strange, because coastal areas are being exposed to the impacts of sea level rise (SLR). It is posing a major threat for coastal cities around the world, as SLR causes a higher chance of flooding, shoreline erosion, salinization and wetland changes (IPCC, 2022, Hu & Deser, 2013; Katsman et al., 2011). In addition, ''SLR is expected to affect economic activities associated with maritime and inland navigation and environmental goods and services which many coastal cities rely upon, such as fishing, shipping or tourism'' (Le Cozannet et al., 2017, p.2).

One of the countries for which SLR adaptation is extremely important is the Netherlands. Many Dutch coastal are located in low-lying areas, making them prone to flooding (Hinkel et al., 2018). Because of this, flood defense structures have been created throughout the years in the form of dikes, dams or storm surge barriers to remain protected from flooding. However, rising sea levels will challenge the current flood defense system. Higher levels of water will occur more frequent, meaning that the chance of flooding will increase as well (Van Alphen, Haasnoot & Diermanse, 2022). ‘‘When the rate of SLR increases up to several centimeters per year, the intended lifetime of a flood defense structure may be reduced from a century to several decades’’ (Van Alphen, Haasnoot & Diermanse, 2022, p.1). Also, the accessibility of the ports in the Netherlands may be affected by SLR. An example of this can be found at the Port of Rotterdam which is largely protected from flooding by the storm surge barrier called ‘Maeslantkering’. ‘’This is an open barrier within the river Meuse, which closes if water level at the outlet of the Waterway exceeds 3 meters. However, closing the Maeslantkering hinders navigation to and from the Port of Rotterdam’’ (Kwadijk et al., 2010, p.735). When sea levels rise, the closing frequency of the Maeslantkering will increase, which has detrimental effects to the accessibility of the port. Besides that, SLR include challenges like salinization and the provision of fresh water (Hinkel et al., 2018). For instance, in the West of the Netherlands, salinization could get worse due to SLR, which will stress the agricultural production and freshwater provision (Hinkel et al., 2019).

Although SLR poses many potential risks for coastal cities in countries like the Netherlands, it should be noted that SLR is a complex and uncertain theme (Hinkel et al., 2018; Nicholls & Cazenave, 2011). This is due to the fact that the extent to which sea levels will rise depend on many factors such as the melting of ice sheets and glaciers and global warming (Scambos & Abdalati, 2022). These factors make it challenging to accurately predict future SLR and the current SLR projections are therefore subject to a degree of uncertainty (Scambos & Abdalati, 2022; Van Alphen, Haasnoot & Diermanse, 2020). Also, SLR will not be uniform across the regions the world, meaning that local adaptation strategies towards SLR can be difficult to realize (Le Cozannet et al., 2017). In addition to that, SLR adaptation is (partly) not seen as a relevant topic, as policy makers experience difficulties to reach citizens and to raise awareness about the impacts of SLR (Vollstedt et al., 2021). According to the report of The Organization for Economic Co-operation and Development (OPEC, 2014), for example, the perception of water risks among the Dutch citizens is low and it is challenging for policy makers to increase the awareness of water related risks.

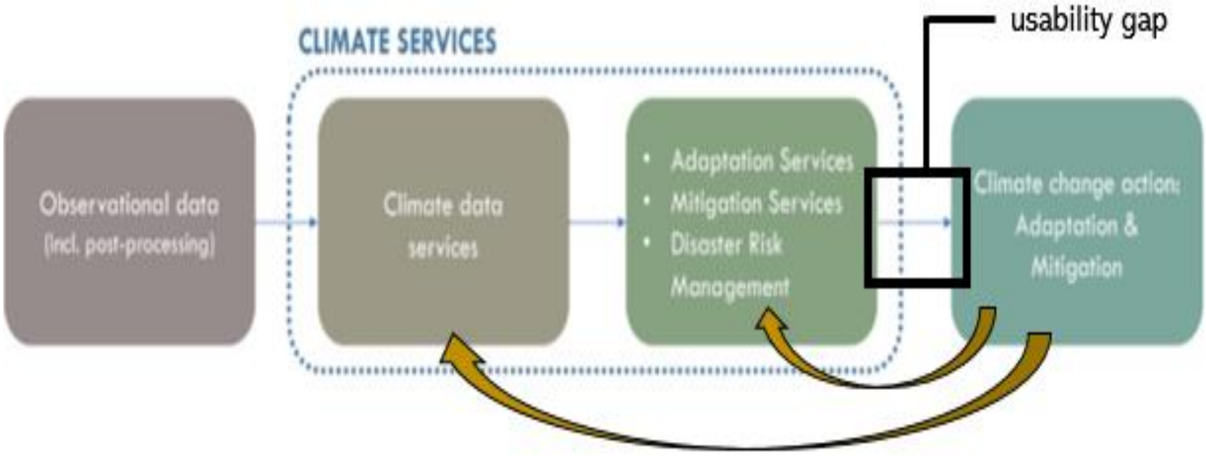
However, human interventions towards SLR consequences will become more costly in the future and the decisions that are made today may have implications for the coming years or decades (Haasnoot et al., 2022; Le Cozannet et al., 2017; OECD, 2014). SLR information is required on both the short and long term to avoid lock-in, path dependency and maladaptation (Haasnoot, Kwakkel, Walker & Ter Maat, 2013; Le Cozannet et al., 2017). Due to this, it is becoming more apparent that coastal climate services (CCS) are crucial for stakeholders such as governmental sides or (regional) water authorities to improve urban resilience towards the impacts of SLR (Vollstedt et al., 2021; Goosen et al., 2013). CCS are basically a type of CS which can be used within coastal areas (Le Cozannet et al., 2017). CCS are needed to help policy makers to understand, to raise awareness and to adapt to climate impacts in coastal areas. In that sense, CCS are needed in order to raise awareness about SLR, to help understanding the impact of it and to support the development adaptation strategies (Vollstedt et al., 2021; Raaphorst et al., 2020; Le Cozannet et al., 2017). Eventually, SLR information could be captured into various CCS like maps, graphs, scenario’s, infographics, reports or figures (Raaphorst et al., 2020).

1.3 Usability gaps within coastal climate services

As described above, CCS are crucial for understanding SLR consequences and for the creation of suitable SLR adaptation solutions (Vollstedt et al., 2021; Le Cozannet et al., 2017). However, it remains uncertain when and to what extent sea levels will rise and SLR impacts could vary across all regions of the world (Van Alphen, Haasnoot & Diermanse, 2020). In addition, ''the capacity to adapt to climate related issues vary greatly between different populations, communities and individuals, depending on the level of vulnerability, resilience and available resources'' (Hansen & Bi, 2017, p353). This makes the adaptation process towards climate related issues such as SLR complex, which could lead to various adaptation problems (Moser & Ekstrom, 2010). For example, it could be unclear for responsible stakeholders (such as regional water authorities, provinces or municipalities) what the long-term impacts of SLR will be on a local level or which adaptation solution will be the most suitable for a specific location. This implies that SLR information should be communicated in a tailored and coherent way, so that various responsible stakeholders are able to use it in order to overcome adaptation barriers (Raaphorst et al., 2020).

An important term that is used for tools like CCS to describe its communicative quality, is 'usability'. This refers to the extent to which humans will use a given tool, product or service (such as a CCS) to achieve certain goals and the extent to which this can be done in a simple and efficient way (Alonso-Rios, Vázques-Garcia, Mosqueira-Rey & Moret-Bonillo, 2010). However, CCS are often not applied by potential users due to, for example, an irrelevant or unsuitable presentation of climate information (Vollstedt et al., 2021; Hoffmann, Rupp & Sander, 2020; Raaphorst et al., 2020; Le Cozannet et al., 2017; McNie, 2012). In other words, a variety of usability gaps can be identified, which means that there is a mismatch between what scientists think is usable information and what stakeholders responsible for adaptation processes think is usable (Raaphorst et al., 2020; Lemos, Kirchhoff & Ramprasad, 2012). According to Van Der Brugge et al. (2019), the location of usability gaps can be found between the CCS itself and the actual use of CCS for SLR adaptation, which is visualized in figure 1 (including the missing feedback loops from the end-users to the producers of CCS). It should be noted that this figure focuses on CS in general, but the same process apply to CCS as it can be seen as a type of CS (Le Cozannet et al., 2017).

***Figure 1**: Categorization of climate services by Hamaker et al. (2017), the location of the usability gap according to Lemos et al. (2012) and the necessary feedback loops (Van Der Brugge et al., 2019, p.11)*



During the last couple of decades, attempts have been made to create more suitable (computer) technologies, products and services to support adaptation processes (Pelzer, 2017). Despite that, it appears that usability gaps still exist in CCS caused by various reasons (Raaphorst et al., 2020; Le Cozannet et al., 2017; Vaughan & Dessai, 2014). For example, the majority of CCS used in Europe are providing information regarding the impacts of climate change and less about the acting phase (Raaphorst et al., 2020; Le Cozannet et al., 2017; Vaughan & Dessai, 2014). Also, when it comes to SLR adaptation, there are various amounts of end-users of CCS which may have differing levels of understanding of scientific information and, crucially, the strengths and limitations of this information in supporting their decisions (Raaphorst et al., 2020). In addition, Lawrence et al. (2021) & Le Cozannet et al. (2017) argue that SLR information provided in CCS is often seen as incomplete, as data on, for instance, salinization is not included. Due to these usability gaps, the information needs of the stakeholders responsible for SLR adaptation are not met by the CCS, meaning that the adaptation process could be hindered (Raaphorst et al., 2020).

1.4 Research aim

In the past couple of decades, a lot of research has been done about the consequences of SLR and the way climate change is accelerating this process (Le Cozannet et al., 2017). Coastal cities are especially in need of adaptation strategies because of SLR and its consequences (Le Cozannet et al., 2017; Vollstedt et al., 2021). Only in the Netherlands, the impacts of SLR could potentially disrupt the functioning of coastal cities, as a lot of social and economic activities can be found in these areas (Van Alphen, Haasnoot & Diermanse, 2020; Hinkel et al., 2018). Therefore, stakeholders responsible for SLR adaptation such as (regional) water authorities or governmental institutes are in need for CCS that could help with the understanding of (local) SLR effects and the creation of suitable adaptation solutions (Le Cozannet et al., 2017).

However, existing CCS regarding SLR information are barely used during adaptation processes (Vollstedt et al., 2021; Le Cozannet et al., 2017; Brasseur & Gallando, 2016). The lack of use of these services is due to so called 'usability gaps', which could be explained by many different factors (Vollstedt et al, 2021; Raaphorst et al., 2020; Le Cozannet et al., 2017). Although usability gaps occur in at all kinds of CS, this research will focus on CCS regarding SLR information as less information has been made available throughout the years that support coastal adaptation (Le Cozannet et al., 2017). Because of this, the goal of this research is to identify the factors that explain the usability gaps within CCS regarding SLR information that are used during the adaptation process in Dutch coastal cities. To be able to do so, the coastal cities of Rotterdam and Vlissingen have been selected to conduct a comparative case study. These cases are relevant for this research, because both Rotterdam and Vlissingen border the North Sea and will therefore be affected by the impacts of SLR. Because of this, CCS are needed in these coastal cities understand the SLR consequences and to create adaptation strategies. In addition to that, this research is part of the European Coastal Climate Core Project (CoCliCo), which means that cities should be selected from a European country.

Existing documents (such as sources for finding available CCS, SLR research programs or policy documents for SLR adaptation) have been used to identify available CCS, to get an understanding of SLR management in Rotterdam and Vlissingen and to investigate which factors influence the usability gaps within the used CCS in these coastal cities. Besides that, interviews have been conducted with stakeholders responsible for SLR adaptation within the selected cases. Regarding Rotterdam, employees working at the water board Hollandse Delta, Rijkswaterstaat West-Nederland Zuid, the municipality of Rotterdam and the Port of Rotterdam have been interviewed. In Vlissingen, interviews have been conducted with stakeholders such as Rijkswaterstaat Zee en Delta, water board Scheldestromen, the province of Zeeland and the municipality of Vlissingen. The results from the interviews provide insights about the factors that influence the usability gaps in the CCS that are used by these responsible stakeholders for SLR adaptation in Dutch coastal cities, which could be a starting point for the creation of usable CCS in the future for SLR adaptation.

1.5 Research question and sub-questions

Based on the written text above, the main research question has been formulated:

''Which factors explain the usability gaps in coastal climate services regarding sea level rise information for Dutch coastal cities?''

In order to answer the main question, multiple sub-questions have been set up.

1. *What are the impacts of SLR for Dutch coastal cities?*
2. *Which of the available CCS regarding SLR information are used by the involved stakeholders?*
3. *What (type of) SLR information is shown in the CCS used by the responsible stakeholders?*
4. *What (type of) information about SLR impacts and/or adaptation do the involved stakeholders need?*
5. *Which usability gaps can be identified in the used CCS within the selected cases?*
6. *Which factors can be identified that influence the usability gaps in CCS regarding SLR information?*

1.6 Scientific relevance

Since the mid-twentieth century, research has been done about climate change and its impacts, resulting in a large amount of available information. To support urban planners and other relevant stakeholders during adaptation processes, the concept of CS emerged only about two decades ago (Le Cozannet et al., 2017). In addition, the World Meteorological Organization established in 2009 the Global Framework for Climate Services that would assist decision makers in understanding climate risks and in creating adaptation solutions (Lawrence et al., 2018). As a result, CS have been created to adapt to climate related issues such as heavy rainfall, heat stress or periods of drought.

When it comes to SLR and coastal adaptation however, less information has been made available even though there is a demand for CCS that could support coastal adaptation (Le Cozannet et al., 2017). Historically, the assessment, planning and design of adaptations strategies in coastal settings are driven by CS like impact or response models, maps or scenarios (Lawrence et al., 2021). It is proven, however, that these CCS are inadequate for supporting decision-making processes in changing coastal setting where sea level change is becoming the dominant driver of change (Lawrence et al., 2021; Hinkel et al., 2019; Le Cozannet et al., 2017; Vaughan & Dessai, 2014). Many researchers (e.g. Lawrence et al., 2021; Vollstedt et al., 2021; Le Cozannet et al., 2017) argue that the way SLR is presented in CCS often does not meet the needs of the end user. Some examples of usability gaps within CCS that have been identified in previous research, include a lack of awareness about the existence of CCS by policy makers, a lack of relevant information as some (local) SLR impacts (e.g., salinization) are not shown in the CCS or a lack of socio-economic information within the CCS related to the consequences of SLR (Le Cozannet et al., 2017; Brasseur & Gallardo, 2016; Vaughan & Dessai, 2014;)

However, this particular problem does not only occur when using CCS in particular, but it is a problem that exist in CS in general (Findlater et al., 2021; Hoffmann, Rupp & Sander, 2020; Raaphorst et al., 2020; Lemos et al., 2012). It can be seen as a mismatch between what climate scientist think is usable information and what policy makers or other relevant stakeholders consider to be usable (Raaphorst et al., 2020). The result is that climate science is not being translated into urban adaptation strategies. However, there is still a lack of understanding on why these usability gaps exist (Findlater et al., 2021; Alexander & Dessai, 2019). It therefore becomes clear that providing insight about the factors which influence these gaps contributes to the scientific literature. By doing so, this research helps to tailor climate science regarding SLR to the information needs of the end-users of CCS, which is needed to create awareness within society regarding this problem and to implement adaptation strategies (Hoffmann, Rupp & Sander, 2020; Vollstedt et al., 2020)

1.7 Societal relevance

It can be said that climate change will cause several economic, social and environmental problems on a global, national and local scale. SLR increases the chance of flooding, shoreline erosion, submergence, salinization and wetland changes (Hinkel et al., 2017; Le Cozannet et al., 2017). Also, SLR poses a distinctive and severe adaptation challenge as it implies dealing with slow onset changes and increased frequency and magnitude of extreme SLR impacts, which could escalate in the coming decades (IPCC, 2022; Scambos & Abdalati, 2022). The European Environmental Agency (2021) adds to this that relative SLR, caused by land subsidence, will make the problem even worse. But even under low carbon emissions, sea levels will continue to rise for centuries, as ice sheet melting and ocean expansion are characterized by long response times (Le Cozannet et al., 2017). To prevent these kinds of problems in the future, it is important to come up with adaptation strategies (Vollstedt et al., 2021; Katsman et al., 2009).

However, adapting to climate related issues such as SLR can be complex in many ways. For example, stakeholders on a national, regional and local level (both public and private) may have different responsibilities when it comes to SLR adaptation (Le Cozannet et al., 2017). Within the Dutch context of SLR management, Rijkswaterstaat and the water boards (regional water authority) have a legal responsibility for maintaining the primary flood defense structures such as dikes or dams, while stakeholders such as provinces or municipalities need to integrate SLR adaptation measures with other spatial interests (Rijksoverheid, n.d). These differences in tasks towards SLR adaptation may hinder the adaptation process. Also, SLR encompasses a long period of time (e.g., IPCC works with models for the coming 50, 100 or even 200 years). But the further one looks into the future, the more uncertain the predictions will be regarding SLR and its potential consequences (Vollstedt et al., 2021; Hoffmann, Rupp & Sander, 2020; Perrette et al., 2013). This uncertainty could hinder the development of adaptation strategies as it is difficult to raise awareness among both decision makers and citizens (Hurlimann et al., 2014; OECD, 2014; Perrette et al., 2013).

To overcome this complexity, CCS are needed that support the decision-making process (Vollstedt et al., 2021). However, end users of CCS are not using or not capable of using these services, which results in various usability gaps (Raaphorst et al., 2020; Lemos, Kirchhoff & Ramprasad, 2012). For example, SLR information or the way it is shown is often seen as unsuitable to serve as a supporting tool for the creation of adaptation strategies, resulting in various usability gaps (Le Cozannet et al., 2017; Vaughan & Dessai, 2014). For example, many CCS only cover ''part of the sea level, biophysical and socio-economic uncertainty and some key coastal datasets, such as salinization or current shoreline changes, remain incomplete'' (Le Cozannet et al, 2017, p.7). Also, SLR information within CCS is often difficult to interpret within the local decision-making context (e.g., at the municipality scale), due to the fact that SLR impacts differ across all regions over the world (Le Cozannet et al., 2017; Brasseur & Gallando, 2016; Vaughan & Dessai, 2014). By providing information about the factors which influence CCS usability, this research can be useful for developing new CCS reagrding SLR information. When doing so, stakeholders responsible for developing adaptation strategies could get a better understanding about SLR, its consequences and how to adapt to it (Vollstedt et al., 2020; Le Cozannet et al., 2017).

1.8 Reading guide

This thesis has been structured in six chapters. Within the first chapter, the research aim, the research question and sub-questions and the scientific and societal relevance are shown. In the second chapter, the theoretical framework is presented in which the central themes and theories are discussed (e.g. CCS, SLR, barriers within climate adaptation processes, the concept of usability gaps and a framework for identifying the factors that influence the usability gaps within CCS). When this is done, an operationalization of the main concepts and a conceptual model will be shown. The third chapter provides the methodology, in which the research philosophy, strategy, methods and data collection and analysis will be explained. After that, the results of the comparative case study (Rotterdam and Vlissingen) will be presented in chapter four. Finally, the sub-questions and the main question will be answered in chapter 5 and a discussion will be shown in chapter 6.

2. Theoretical framework

Within this section, the central concepts and theories will be discussed as it provides a basis for answering the research question. These concepts will be explained and supported by academic literature. After that, an operationalization of the concepts and a conceptual framework will be presented.

2.1 Defining coastal climate services regarding sea level rise information

Humans have always faced climate related risks and as we look into the future, human welfare will increasingly depend on the extent to which climate risks and opportunities are being dealt with. When it comes to improving the capacity to manage climate related risks, CS are seen as an important part (Vaughan & Dessai, 2014; Weaver et al., 2012). As CS are to continuously rise in prominence on regional, national and global level, it is important to re-examine what exactly is meant by CS (World Meteorological Organization, 2022). Based on academic literature, it becomes clear that the term CS has been described in different ways (Raaphorst et al., 2020 Lourenço et al., 2015).

For example, The Global Framework of Climate Services (GFCS, n.d.) described CS as ‘’climate information provided in a way that assists decision making by individuals and organizations’’. Another definition is provided by the Climate Services Partnership (CSP), which states that CS refer to ‘’the production, translation, transfer and use of climate knowledge and information in climate informed decision making and climate-smart policy and planning’’ (Brasseur & Gallardo, 2016, p.80). Besides that, the European Commission (2015) provides a definition by quoting that ‘’CS are the transformation of climate related data into customized products such as projections, forecasts, information, trends, economic analysis, assessments, counseling on best practices, development and evaluation of solution, and other services in relation to climate that may be of use for society at large’’ (Brasseur & Gallardo, 2016. P.80).

Throughout many years, CS that have been developed entail a variety of tools, such as maps, projections, scenarios, graphs and assessments (Raaphorst et al., 2020). Vaughan & Dessai (2014) state that these communication tools need to deliver timely, tailored information and knowledge to decision-makers. To be more precise, the goal of CS could be to provide information about the impact of climate change such as heat stress, flood risks, periods of drought. It is also possible that the goal of the CS is to support different end users like politicians, managers, private enterprises or inhabitants in adapting and mitigating to the consequences of climate change (Global framework for climate services, n.d.; Lourenço, et al., 2015). To combine both elements, CS can also be defined as ‘’information services that provide information about climate change, climate impacts and climate adaptation strategies for decision-makers and other stakeholders to create understanding, to raise awareness, and to make decisions regarding tailored adaptation solutions in specific areas (Raaphorst et al., 2020, p.2). Within this research, this definition for CS will be used as both the understanding of climate change consequences and adaptation solutions to these impacts are included. This is needed because stakeholders responsible for climate adaptation can experience usability gaps during these ‘phases’ (Raaphorst et al., 2020).

Climate services (CS):

‘’Information services that provide information about climate change, climate impacts and climate adaptation strategies for decision-makers and other stakeholders to create understanding, to raise awareness, and to make decisions regarding tailored adaptation solutions in specific areas.’’

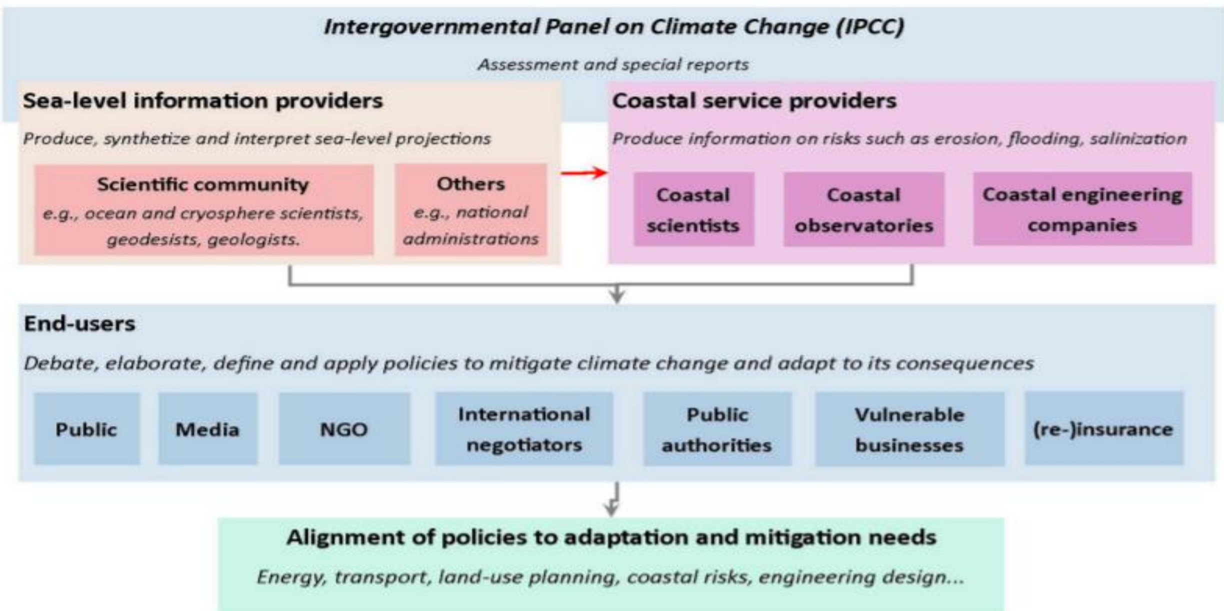
Now a description of the term CS is given, it is possible to zoom into *coastal climate services (CCS).* CCS are basically just a type of CS which are, according to Le Cozannet et al. (2017), used in coastal areas. In this sense, coastal areas generally refer to zones that are located either directly to the coast or in an estuary (Le Cozannet et al., 2017). However, just like any other CS, it remains challenging to define CCS and to characterize the users and providers (Le Cozannet et al., 2017). For example, coastal areas around the world may have different needs when using the CCS due to different risk perceptions, institutional settings regarding coastal management, policy making processes or economic possibilities (Vaughan and Dessai, 2014). In that sense, it could be that CCS should provide insights for responsible stakeholders about the consequences of SLR and the ways to adapt to it, in order to create understanding, raise awareness or to make decisions regarding SLR adaptation solutions in coastal areas. This definition for CCS (which is basically the same definition used for CS, but more specified for coastal areas) will be used in this research.

Coastal climate services (CCS):

''Information services that provide information about climate change, climate impacts and climate adaptation strategies for decision-makers and other stakeholders to create understanding, to raise awareness, and to make decisions regarding tailored adaptation solutions in coastal areas.''

To frame it a bit further, this research focuses on ***coastal climate services regarding sea level rise information***. This distinction needs to be made because not all CCS are providing information regarding SLR, although many of them do. The way these CCS are provided can take multiple legitimate forms. It is possible to provide direct accessible climate data for SLR, charts of climate statistics of the global mean SLR, products that respond to certain needs such as a story map to explain SLR impacts and detailed datasets to enable others to expand existing knowledge with their own datasets or processing (Le Cozannet et al., 2017). In the figure below, a projection of the producers and possible end-users is shown for sea level projections. Within this research, only the end-users of the CCS will be relevant, as the goal of the research is to investigate the factors that influence the usability gaps that are experienced by the stakeholders responsible for SLR adaptation.

figure 2*. Current projection of (end-)users and producers for sea level projections (Le Cozannet et al., 2017, p.5)*

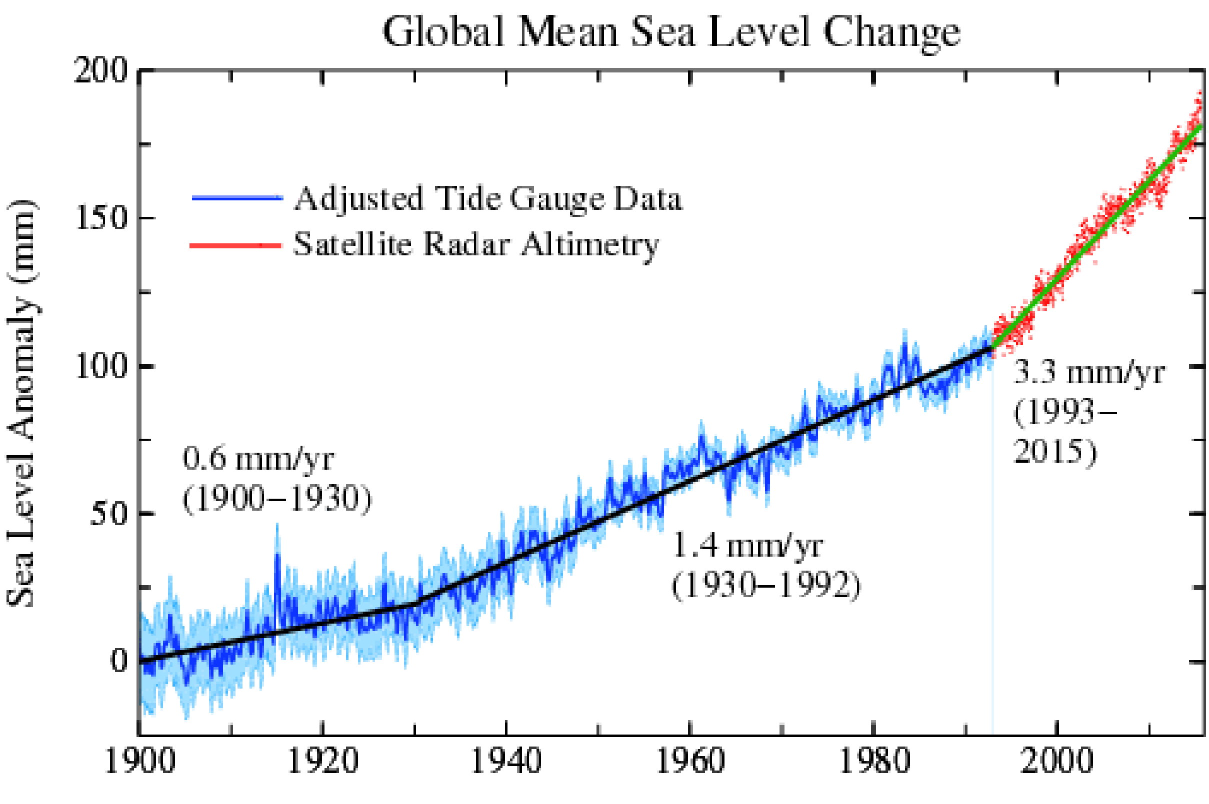


2.2 SLR consequences in coastal cities

Now a definition has been provided for the term CCS, it is important clarify what the consequences of SLR could be. SLR and its impacts on coastal zones have become in the recent years a question of growing interest in the scientific community, as well as the media and public (Cazenave & Le Cozannet, 2013). According to Scambos & Abdalati (2022) Cazenave & Le Cozannet (2014), the current global mean SLR is caused by thermal expansion of sea waters, land ice loss, and freshwater mass exchange between oceans and land water reservoirs. This leads to many different consequences such as beach erosion, flooding and inundation, loss of wetlands and marshes (Ingebritsen & Galloway, 2014; Barron et al., 2012; Moser, Williams & Boesch, 2012). Besides that, relative SLR is also occurring due to land subsidence as ground water is continuously abstracted for other purposes (Ingebritsen & Galloway, 2014; Nicholls, 2011). Relative SLR has many potential impacts, including higher (extreme) sea levels, coastal erosion, salinization of surface and ground waters, and degradation of coastal habitats such as wetlands (Nicholls, 2011).

SLR impacts are expected to become more frequent and severe in the future, as sea levels are likely to rise for many centuries at rates higher than that of the current century due to climate change (Scambos & Abdalati, 2022; Hinkel et al., 2018; Cazenave & Llovel, 2011). ''During the twentieth century, the averaged global SLR was about 1.5 (1.1–1.9) millimeter per year, which was primarily due to warming of the upper ocean (thermal expansion) but with a contribution from glacier loss. More recently, the rate of sea level rise has increased to a present value of about 3.3 millimeter per year (measured during 1993-2015), mostly due to increasing losses from glaciers and the Greenland Ice'' (Scambos & Abdalati, 2022, p.123). In addition to that, the extent to which sea levels will accelerate in the future depend on the cumulative amount of CO^2 emissions (Van Alphen, Haasnoot & Diermanse, 2022; Clark et al., 2016). The earth atmosphere and oceans are warming up due to the emission of greenhouse gasses, which eventually causes sea levels to rise (Van Alphen, Haasnoot & Diermanse, 2022).

Figure 3*: Global mean sea level change (Climate Etc., 2018)*



In the last few decades, the rapid growth of coastal cities has resulted in larger populations and more valuable coastal property being at risk from SLR impacts (Nicholls, 2011; Yin, Griffies & Stouffer, 2010). This growth is expected to continue, which brings a greater likelihood of increased property damage in coastal area with it. Especially low-lying areas are being considered to be ‘risky places’, according to Nicholls (2011), as these places are more reliable on existing technological flood defenses and drainage. However, SLR impacts will not be the same in all coastal areas, but rather show complex patterns, as indicated by available observations. ‘’As a result, some regions could experience local SLR considerably faster and larger than the global mean, whereas the local SLR elsewhere may be well below the global mean or even negative’’ (Yin, Griffies & Stouffer, 2010, p.4585). Perrette et al. (2012) add to this that it is possible that local sea levels strongly deviate from the global mean sea levels due to changes in wind and ocean current. Due to this, information needs of stakeholders responsible for SLR adaptation could vary among coastal areas (Le Cozannet et al., 2017).

2.3 SLR research and adaptation in the Netherlands

Because this thesis focuses on Dutch coastal cities, an overview needs to be given about SLR research and adaptation in Netherlands. This is needed, because the use of CCS depends on the context in which planning processes of climate change are being arranged (Raaphorst et al., 2020). Many coastal areas of the Netherlands are built below sea level, causing them to be vulnerable to flooding (Van Alphen, Haasnoot & Diermanse, 2022). Major flood events have occurred in the past, as parts of the province of Zeeland and South Holland have been flooded in the year of 1954 for instance. This event eventually led to the establishment of the Delta Works (a project in which 3 locks, 6 dams and 5 storm surge barriers had been built) and higher standards for the dikes were set for all dikes throughout the country, in order to prevent a similar flood disaster to happen (Rijkswaterstaat, n.d). The protection system towards flooding is nowadays very strong and the chance of a flooding is extremely low (Hinkel et al., 2018). However, rising sea levels would mean that the chance of flooding will be higher and that the current flood protection system will be challenged more often in the future (Van Alphen, Haasnoot & Diermanse, 2022; Hinkel et al., 2018).

However, SLR could impose other impacts on Dutch coastal cities as well. A rise in sea levels would affect, among other things, the fresh water supply as saltwater intrusion coming from the North Sea is more likely to happen (Hinkel et al., 2018). Besides that, SLR has an impact on ports, shipping, recreation, agriculture and nature, meaning that the role of spatial adaptation will become more important (Van Alphen, Haasnoot & Diermanse, 2020; Hinkel et al., 2018). For instance, SLR could affect the accessibility of ports, which means that ports need to adapt spatially to avoid economic losses. It could also be that agriculture and nature would suffer from an increase in the level of salinization imposed by SLR, meaning that urban adaptation solutions are needed for this as well (Nationaal Deltaprogramma, n.d.). In order to stimulate climate adaptation measures, the National Government has started the National Delta Program in 2008. The goal of this program is to provide a policy framework in order to protect the Netherlands against flooding, to arrange a sufficient amount of freshwater throughout the country and to contribute to a climate-proof and water-robust use of land (Nationaal Deltaprogramma, 2022). Also, The Netherlands has decided in 2015 within the Delta Decision for Spatial Adaptation (Deltabeslissing Ruimtelijke Adaptatie) that national governments, provinces, municipalities and water boards will jointly work towards a climate proof and water-resilient country by the year of 2050 (Deltaprogramma, n.d.).

During the last couple of decades, some large research programs have been established with regards to climate change. When it comes to climate change in general, research programs like the National Program for Spatial Adaptation to Climate Change (ARK, 2004-2011), Knowledge for Climate (2007-2014) or the program of National Water and Climate Knowledge and Innovation (NKWK, since 2016) were created. Within these programs, adaptation strategies haven been developed for a more sustainable spatial environment, in order to create resilient and robust cities towards all kinds of consequences of climate change (such as SLR, heat stress, periods of drought or inundation). Regarding SLR specifically, Dutch research has evolved over time, which is mainly due to the new technologies and methods that have become available (Rijkswaterstaat, n.d.). Over the years, this research has become more sophisticated and includes computer modeling, satellite observations, and field data collection (Rijkswaterstaat, n.d.). As the risks posed by SLR have become more apparent, Dutch research has increasingly focused on predicting future sea level changes and the impacts of these changes on coastal communities, infrastructure, and ecosystems (Kwadijk et al., 2010). For example, computer models have been used to simulate SLR impact, as well as the response of coastal systems to rising sea levels. Besides that, vulnerability assessments and risk assessments have been used to identify areas and populations that are most at risk from SLR and to prioritize adaptation measures (Kwadijk et al., 2020; Nationaal Deltaprogramma, n.d.).

In 2009, The Netherlands have introduced the SLR knowledge Program (Kennisprogramma Zeespiegelstijging), in which the effects of SLR are being investigated and strategies are being made. This is also part of the National Delta Program, in which the created strategies for the protection towards flooding, the provision of fresh water and for climate-proofing the Dutch cities are being explained (Nationaal Deltaprogramma, 2022). Within the SLR Knowledge Program, government authorities, research institutes, businesses, planners, and NGOs are expanding expertise on the potential rise in sea level, namely its pace and magnitude, the consequences for flood defenses systems, freshwater supply, spatial planning and ways to anticipate such consequences in time (Nationaal Deltaprogramma, n.d.). Eventually, the goal is to provide policymakers with the information and tools they need to develop effective and sustainable solutions to address the challenges posed by SLR. Research has been done in five different tracks, which are stated below (Nationaal Deltaprogramma, n.d.).

- Track I: What is the influence of Antarctica on global SLR?
- Track II: To what extent is it necessary to tighten up the measures regarding SLR, which are included in the National Delta Program?
- Track III: When is (earlier) action necessary against SLR?
- Track IV: What are the scenarios for the rate and magnitude of SLR in the distant future?
- Track V: What is needed in terms of communication, participation and organization?

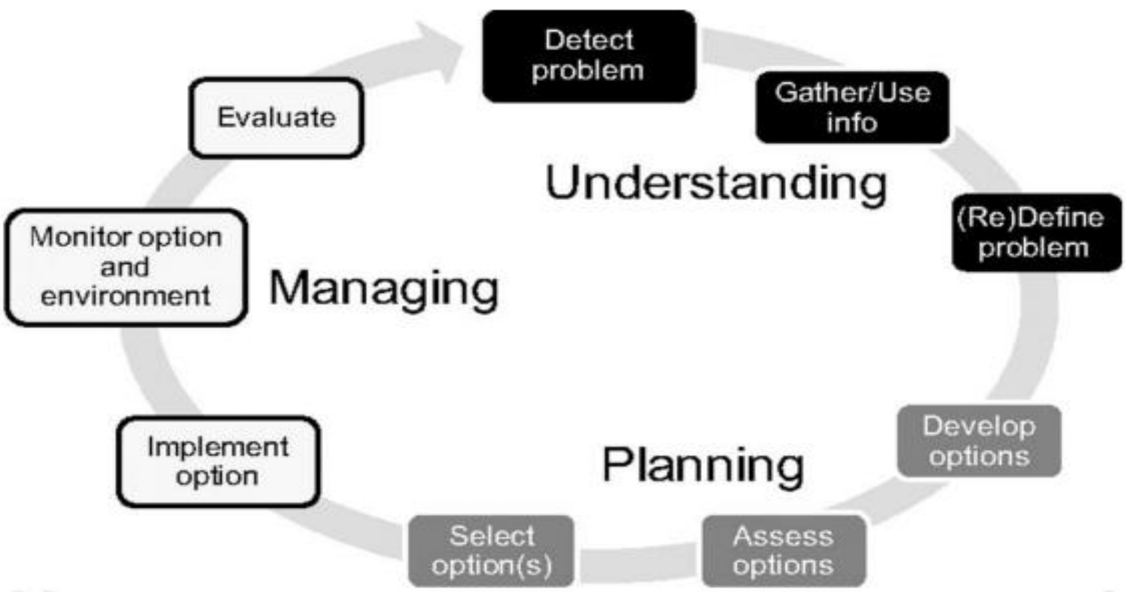
2.4 Identification of SLR adaptation barriers

As described above, SLR could lead to many different consequences, meaning that there is a demand for a variety of adaptation solutions as well. According to Ayers & Dodman (2010, p.161), climate adaptation can be defined as ''*the adjustment in natural or human systems in response to actual or expected climatic effects, which moderates harm or exploits beneficial opportunities*''. Adaptation can be a process, action or outcome within a particular system (ecosystem, household, community, group, sector, region, country) that helps the system to better cope with, manage or adjust to the changing conditions, stresses, hazards, risks or opportunities associated with climate change (Smit & Wandel, 2006). Also, adaptation strategies could range from short term to long term coping and differ from national to local areas (Moser & Ekstrom, 2010). However, the creation and implementation of SLR adaptation strategies can be quite complex. For instance, SLR projections and expectations are considered to be highly uncertain, even though it is inevitable that sea levels will rise (Hurlimann et al., 2014). Some papers suggest that the possibility of an average rise in sea levels of 2 meters by the year 2100 should be given serious considerations. Other papers argue that the statistic validity of the used approaches is questionable (Pardaens, Gregory & Lowe, 2010). Besides that, the possibilities for climate adaptation varies between different populations, communities, and individuals, depending on levels of vulnerability, resilience, and available resources'' (Hansen & Bi, 2017, p.353).

This complexity makes the SLR adaptation difficult, as it remains unknown to what extent sea levels will rise. This could cause all types of adaptation barriers that hinder or delay the implementation of adaptation measures or even exclude the issue from the policy process (Uittenbroek, Jansen-Jansen & Runhaar, 2013). According to Moser & Ekstrom (2010, p.22027), barriers can be defined as ''obstacles that can be overcome with, among other things, concerted effort, creative management, change of thinking, prioritization, and related shifts in resources, land uses or institutions''. Uittenbroek, Janssen-Jansen & Runhaar (2015, p.402) add to this that ''the policy process including climate adaptation can expect barriers that are social, cognitive, financial, technological and organizational/institutional in nature''. Barriers can also lead to missed opportunities or higher costs in the future (Moser & Ekstrom, 2010). Although overcoming all adaptation barriers is not a guarantee for an adaptation success, it can be said that ignoring certain best practices (e.g. effective stakeholder analysis or providing reliable climate information) could lead to maladaptation (Moser & Ekstrom, 2010).

The adaptation barrier can be seen as an information need of the end-user, because the stakeholder responsible for climate adaptation has a demand for climate adaptation knowledge. Many of these barriers can be overcome by using CCS, which help decision-makers to make well-informed decision. But in order to do so, the adaptation barriers need to be identified first, which can be done by using the model proposed by Moser & Ekstrom (2010). Within this model, a distinction is made between the understanding, planning, and management phase of the climate adaptation process. This performance of the climate adaptation process can be seen as cyclical and continuous (Uittenbroek, Janssen-Jansen & Runhaar, 2013). Although the system of concern may produce signals of change, it is in the end the actors, the governance system and the larger context that affect the identification, perception and interpretation of adaptation barriers (Moser & Ekstrom, 2010). Adaptation barriers can arise in each of the three concepts of understanding, planning and managing. It is important to provide a better understanding of these concepts, as it basically can be referred to the information needs of the stakeholders responsible for climate adaptation processes. The understanding, planning and management phases are discussed in more detail below.

***Figure 4**: Phases and subprocesses throughout the adaptation process (Moser & Ekstrom, 2010, p.22027)*



2.4.1 Understanding phase

Moser & Ekstrom (2010) have subdivided the understanding phase into the detection of the problem, the gathering of information/data and the (re)definitions of the problem. When it comes to the detection of the problem, it is possible that the issue is not being detected in the first place. It could happen that there is no or too little data available, that the message does not reach the actors, that the actors involved do not perceive the message as a 'problem' or that the responsible stakeholders do not perceive a feasible option. Barriers can also occur when gathering information and data. Climate information must have a clear interest and focus and should be available and accessible. Besides that, when actors are gathering information, the relevance, credibility and trust of the data should be guaranteed. Lastly, the (re)definition of the problem itself can also be a barrier. It could be that responsible stakeholders do not perceive the given information as problematic, do not perceive action taking to be necessary, do not perceive any feasible option or cannot find an agreement. When a barrier occurs within the understanding phase, stakeholders will not go further to the planning phase (Moser & Ekstrom, 2010).

2.4.2 Planning phase

According to the proposed framework of Moser & Ekstrom (2010), the planning phase can be subdivided into the development, assessment and selection of options. During the development of options, it is possible that a barrier emerges when the involved stakeholders are not able to identify certain goals or criteria to solve the problem. Another example given by Moser & Ekstrom (2010) is that stakeholders lose the control over the process or the selected options. When it comes to the assessment of options, it is possible that there is not enough data available or that stakeholders do not have access to the needed information. Lastly, during the selection of options, adaptation barriers could arise when choosing a strategy or it could happen that the involved stakeholders perceive the selected option as unfeasible (Moser & Ekstrom, 2010). When a barrier occurs within the planning phase, involved stakeholders will not go further to the management phase (Moser & Ekstrom, 2010).

2.4.3 Management phase

The third phase of the model proposed by Moser & Ekstrom entails the management phase. This phase has been subdivided into the implementation of options, the monitoring of the options and environment and the evaluation. Considering the implementation of options, problems could occur as stakeholders could face difficulties regarding certain institutional path dependencies, legal or feasible procedures. During the monitoring of the problem, adaptation barriers could occur if, for example, stakeholders do not have the required technology for monitoring. Lastly, an evaluation is going to take place to make sure the implemented option has been effective. Problems within this subdivision could arise as, for example, there are legal limitations for reopening prior decisions, there is no feasible evaluation framework, or there is a lack of expertise and data to come up with a methodology for an evaluation.

2.4.4 Critics about the policy cycle

There are some critics to the approach regarding climate adaptation processes that is proposed by Moser & Ekstrom (2010). Within the European planning tradition, the traditional linear approach of formulation goals, design of alternatives, evaluation and establishing a particular plan has been shifted towards a more cyclical and continuous planning methods (Van Stigt, Driessen & Spit, 2015). ''However, it is impossible to predict in a cyclical approach which knowledge is needed at any time during the planning. If the planning process is completed in a much more chaotic and recurring manner, rather than in neatly separated phases in a linear approach, it is not possible to provide the required knowledge in any structured way'' (Van Stigt, Driessen & Spit, 2015, p.170). Also, in other environmental assessment literature, decision making is rather seen as a linear and rational process consisting of consecutive phases (Cerreta & Torro, 2010). On the contrary, a linear approach may be too simplistic to describe the adaptation process within certain governance structures. For example, when new knowledge is provided during the managing phase, it is possible that this could lead to new ways of understanding, making it a more cyclic and iterative process. Especially when it comes to complex developments, such as the adaptation to SLR, the process goes back and forth and decisions are frequently reconsidered (Van Stigt, Driessen & Spit, 2015). Because of this, the cyclic and continuous model proposed by Moser & Ekstrom (2010) will be suitable for conducting this research.

2.5 Usability gaps within CCS regarding SLR information

In the previous section an outline has been given about the identification of (SLR) adaptation barriers. To overcome these barriers, stakeholders responsible for adaptation processes have become more dependent on (digital) tools or services, especially when confronted with complex climate related problems like SLR. The challenge is therefore to meet the information needs of a diversity of decision-makers by creating 'usable' climate information. However, this raises the questions of how to define concept of usability and how usability gaps can be identified within CCS regarding SLR information.

2.5.1 What is meant by the concept of 'usability'?

When comparing academic literature, it can be noted that the term usability is often used for describing the interaction between humans and given object, referring to people's use of a software application, website, map, book, tool, machine, process, vehicle or any other service. Its goal is to quantify how well users can use or interact with a given (software) product or service (Grier et al., 2013). It is about thinking of how and why people use a certain product or service, making it a user-centered approach. ''Even when a product performs flawlessly, if a user cannot work with the product, then that product has failed'' (Grier et al., 2013, p.68). For example, when a map shows SLR impacts perfectly but the potential end-user is not able to understand how to read the map, it is not usable. According to Alonso-Rios (2010, p.53), usability actually derives from 'user friendly', referring to an expression used to describe systems or services which are designed to be used in a simple way by untrained users, by means of self-explanatory or self-evident interaction between user and computer. However, the term 'user friendly' was criticized for being too limited because it suggested that the needs of the users can be described by only using a single dimension (Alonso Rios et al., 2010). Due to this, the concept of usability was created in order to overcome this limitation.

Nevertheless, Usability is on its own still a vague terminology. Many researchers have tried to break it down into multiple dimensions, in order to create a quality model for the interaction between humans and science. From this point on, it becomes clear that there is no precise definition that is widely accepted and applied in science (Alonso-Rios, Vázques-Garcia, Mosqueira-Rey & Moret-Bonillo, 2010; Tractinsky, 2017). According to Tractinsky (2017), usability can be seen as a so called ''umbrella construct''. Such constructs are prevalent in the scientific fields, but these are at the same time broad, diverse and lack a unifying scientific paradigm (Tractinsky, 2017). ''Given the lack of consensus in the usability field, existing classifications are clearly divergent. Furthermore, when classifications do overlap, they tend to do so only partially and unevenly, with different terms used to designate the same attribute or with the same term used to describe different concepts'' (Alonso-Rios et al., 2010, p.56). Manakhov & Ivanov (2016) add to this that the provided definitions for the concept of usability are often seen as vague or too general to serve as a basis to describe this desired quality of a software tool or service. This is a major obstacle for the implementation of user-centered services in the real world (Manakhov & Ivanov, 2016). To be able to understand the usability of CCS, it is therefore important to provide multiple explanations for the term usability, to compare them and eventually to make use of the most suitable definition.

Throughout the years, many descriptions for usability have been given, which often have been changed in later stages. For example, Nielsen and Loranger (2006) have broken the concept of usability down into learnability, efficiency, memorability, errors, and satisfaction (in Alonso-Rios et al., 2010). In this case, it can be referred to 'how well the users can use a certain functionality'', without mentioning whether a product can be used effectively. Preece et al. (1993), on the other hand, have developed an initial classification that included the attributes like safety, effectiveness, efficiency, and enjoyableness (Preece, Benyon, Davies, Keller, & Rogers, 1993, in Alonso-Rios et al., 2010). Another way of defining usability is given by Quesenbery (2001, 2003, 2004), who described a usable product with the item's effectiveness, efficiency, engagement, error tolerance, and ease of learning. All these definitions contain items that need an explanation in themselves, it can be said that usability is mainly seen as an overarching term. Apart from that, it should be noted that these definitions for usability can be used for all types of software, products, tools or services. Considering this research, it is needed to understand what usability means with regards to SLR information in CCS.

According to Pelzer (2017, p.84), ''more attention has been paid in the last two decades to how planning support tools can not only to describe and predict spatial reality, but also to help urban planners''. However, Brömmelstroet (2013, p.85) argues that ''there is a lack of consistent and structured reporting on the effectiveness of the approaches in improving the performance of planning support systems or services''. Pelzer (2017), agrees on this, stating that it is not very clear how the performance of planning supporting tools is being measured throughout the years. This (again) has led to multiple definitions for usability. For instance, a planning support system or service is considered be usable if it provides ''dedicated information, knowledge and instruments to enlighten (that is, make faster, improve quality, increase ease of performance, etc.) planning tasks and activities'' (Geertman, 2006, p.863, in Brömmelstroet, 2013). Pelzer (2017, p.87) uses the definition of Nielson and Loranger (2006), who argue that usability entails ''how well users can interact with the planning support system or service'', without taking into account whether certain goals can be achieved in an effective way. Lemos, Kirchhoff & Ramprasad (2012), on the other hand, use a completely different approach for defining usability for climate information, as three dimensions of fit (reliability, credibility, saliency), interplay (how new knowledge interplays with other kinds of knowledge) and interaction (between producers and users) are being used.

2.5.2 Usability within this research

As described above, there is no unifying definition for the term usability. The International Organization for Standardization (ISO) has therefore tried to produce and represent a consensus on this term (Bevan et al., 2016). The definitions of usability provided by the ISO are most widely used across the world (Alonso-Rios et al., 2010). However, this does not imply that the way ISO is describing usability is the 'best definition'. It is basically an agreement among many scientists regarding this terminology and this consensus could change over time. Despite that, the definition of the ISO 9241 (which is also the most recent definition of usability) has been used as well within this research, as this definition can be used for all sorts of tools or services (such as CCS). Also, the ISO provides similar concepts that have been used in scientific papers of Brömmelstroet (2013), Pelzer (2017) and Lemos, Kirchhoff and Ramprasad (2012) for describing the usability of planning supporting tools and climate information. According to the ISO (2018), usability can be described as "the extent to which a product, service or system can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use''. Usability, in this context, entails not only whether the end-user is able to achieve his or her goals by using the CS, but also whether he or she is able to use the product is easy and efficient to be used.

***Figure 5**: Usability (Web Wise Wording, 2020)*

- ***Effectiveness***
- ***Efficiency***
- ***User satisfaction***

Effectiveness means the extent to which end-users can achieve all his or her goals in a complete and accurate way by using the product or service (ISO, 2018; Bevan et al., 2016). In this research, it is about how well SLR information solves the challenges the end-user faces by using the CCS. For example, if a user wants to know detailed information about SLR effects on a particular area and the CCS provides that information, the service is considered to be effective.

When it comes to efficiency, it generally refers to whether the user of a product or services spares time when completing a task (ISO, 2018; Bevan, 2016). It can also refer to the amount of resources that should be spent (such as time or money) in order to make use of the product or service. For instance, when it takes too much time to find SLR information, users of the CCS are not going to use it anymore as user want answers on their information needs quickly. An aspect that should be considered is that the efficient use of a product or service depends on the understanding of the users and how they prefer to work (ISO 9241, 2018; Bevan et al., 2016).

Lastly, user satisfaction is about the physical, cognitive and emotional response of the end user when making use of the service. It also refers to the extent to which the expectations of the end-user are being met (ISO, 2018). According to Bevan et al. (2016, p.270), user satisfaction has been redefined to take account of the wider range of concerns that are now recognized as important for user experience: “Positive attitudes, emotions and/or comfort resulting from use of a system, product or service”. To put in another way, user satisfaction considers that humans are not interested in putting a lot of effort understanding the way a functionality or object works and generally prefer things that are easy to do (Bevan et al., 2016). When it comes to user satisfaction in this research, it can be referred to the accessibility and the ease of use of the CCS. The latter mean extent whether users think the CCS is easy and/or pleasant when interacting with. For instance, a technician could be satisfied with a graph or table to understand SLR effects, while a citizen would be more satisfied with an appealing interactive map or storyline.

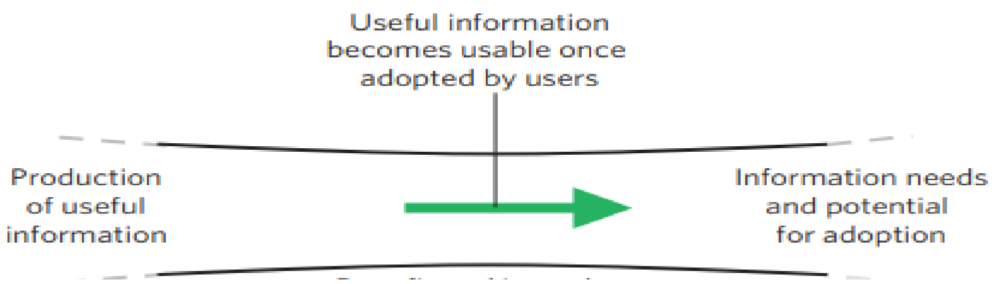
Usability of CCS:

''The extent to which a CCS can be used by specified users to achieve specified goals with effectiveness, efficiency and user satisfaction in a specified context of use.''

2.5.3 Identifying the usability gaps within CCS

Within CCS, complex information should be translated and/or shown in such a way that policy makers can use it for the creation of adaptation strategies. However, ''producers and users are far from homogeneous in the way that they produce and use climate information and it is precisely these different perceptions and understandings usable that create the usability gap reflected in the low level of climate information use in the real world. Producers of climate information may have the assumption that knowledge is useful, but because they do not completely understand or know potential users' decision-making processes and contexts, the knowledge produced remains 'on the shelf'. Users, in turn, may not know or may have unrealistic expectations of how knowledge fits their decision-making and choose to ignore it'' (Lemos, Kirchhoff & Ramprasad, 2012, p.789). Lemos, Kirchhoff & Ramprasad (2012) add to this that all kinds of produced climate information are in some way useful, but climate information is only usable once it is adopted by the users.

Figure 6*: Visualization of useful and usable information (Lemos, Kirchhoff & Ramprasad, 2012, p.791)*



This raises the question, however, how to identify a usability *gap*. To be able to realize a successful communicative CCS, the provided information should be linked to the information needs of the end user (Raaphorst et al., 2020; Lemos, Kirchhoff & Ramprasad, 2012). Coastal areas around the world may have different needs when using the CCS due to different local SLR impacts, risk perceptions, institutional settings regarding coastal management, policy making processes or economic possibilities (Vaughan and Dessai, 2014). These information needs can, for example, arise during the understanding, planning or managing phase of the SLR adaptation process (Moser & Ekstrom, 2010). The stakeholder responsible for SLR adaptation should be given information in such way that it can use the CCS in terms of effectiveness, efficiency and user satisfaction within a specific context of use. However, when a CCS fails to meet the information needs of the end user (in terms of effectiveness, efficiency, or user satisfaction), a usability gap can be found.

Usability gap within CCS

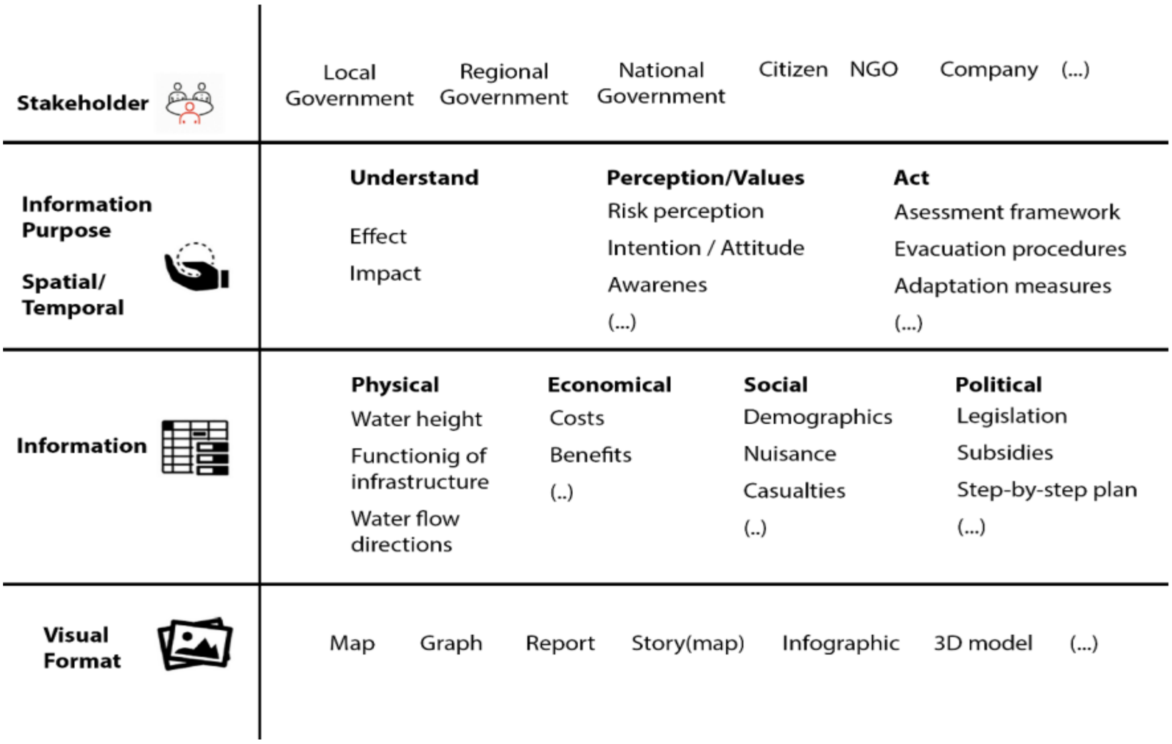
''CCS fails to meet the information needs of specified users in terms of effectiveness, efficiency or user satisfaction in a specified context of use''

For example, it is often mentioned that end-users (e.g. municipalities or provinces) are not able to interact with CCS, because these services focus only on the primary impacts of climate change and less on possible adaptation solutions (Vollstedt et al., 2021; Le Cozannet et al., 2017). In this example, the end users cannot use the CCS effectively because the CCS does not provide SLR adaptation solutions. To put it differently, a usability gap can be found in the category of effectiveness, as end users are not able to use the CCS to achieve their goal. Another example is provided by Lemos, Kirchhoff & Ramprasad (2012), who argue that people often do not know how or when to use climate knowledge in decision-making processes, because the provided information within the CCS is seen as too technical. A climate scientist could think a technical report will be valuable for urban planning practices, but to an untrained citizen, the same report could appear as too difficult or too technical (Raaphorst et al., 2020). In this example, a usability gap can be found within the category of user satisfaction, as the CCS is not easy to use or understand.

2.6 Framework for identifying the factors that influence the usability gap

As described above, various usability gaps could occur when making use of CCS. A template that could be helpful in identifying and explaining usability gaps in CCS regarding SLR information, is the Climate Information Design (CID) as developed by Raaphorst et al. (2020). This framework provides a critical perspective on visual communication in climate adaptation processes. Also, it assumes that visualizations have an implicit or explicit goal and that the quality of visualizations as communication tools depends on the extent to which that goal is achieved (Raaphorst et al., 2020). In order to provide consistent visual communication, the following elements needs to be considered (Raaphorst et al., 2020).

***Figure 7**: Climate information design (CID) (in Raaphorst et al., 2020, p.5)*



1. The desired interpretation by its intended audience (**stakeholders**)
2. The framing of a message for a specific audience with a specific purpose in mind (**purpose**)
3. The appropriate information (**Information**)
4. The readability of the choice of visual expression and appropriate medium of presentation (**visual format**)

Within each element (stakeholder, purpose, information and visual format), different sub-factors are mentioned. By doing so, different actors can be identified, which all need a different purpose of the CCS, different information or a different visual format.

2.6.1 Stakeholder

The first category of the CID framework refers to the stakeholders (or the targeted audience). During decision-making processes, there are often multiple stakeholders involved with different kinds of information needs. According to the CID framework, it needs to be clear who the relevant stakeholders are (Raaphorst et al., 2020; Hine et al., 2014). Figure 4 shows examples like the local, regional or the national government, citizens, NGO's and businesses. During decision-making processes, a CCS should affect the 'right' or 'appropriate' audience, in order to be usable. This means that the CCS should target the stakeholders that are responsible for understanding SLR impacts or creating adaptation solutions. Besides targeting the appropriate audience, it should be clear if stakeholders are able to understand the provided information. However, SLR responsibilities might be divided among various (governmental) institutions. Considering the Dutch context for SLR management, there are different responsibilities for stakeholders such as water boards, Rijkswaterstaat, provinces, municipalities or ports. It could be that technical information about the impact of SLR on the current dike system is suitable to fulfill the task of water boards, but this information might be useless for municipalities which need information for spatial adaptation solutions.

2.6.2 Purpose

Besides paying attention to the stakeholders, the purpose of the CCS should also be clear. The (information) purpose can be defined as the goal of the CCS when providing climate information (Raaphorst et al., 2020). However, it is important to keep into mind whether this particular goal is in accordance with the information needs of the end user, as the goal of the CCS should be relevant for the problem stakeholders are using the CCS for (Cash & Belloy, 2020; Lemos, Kirchhoff & Ramprasad, 2012). The goal of a CCS could be, for instance, to provide information about the understanding of possible SLR impacts (e.g. flooding, salinization) or to provide information about suitable adaptation strategies. However, if the goal of the CCS is not in line with the information needs of the involved stakeholders, the information within the CCS can be seen as irrelevant.

The purpose is associated with a spatial or temporal dimension as well. This refers to whether the provided information can be seen as usable in terms of time and space, which is also linked with the relevance of information. During the adaptation process towards SLR, stakeholders have information needs for specific areas within a given period of time. For example, when a CCS provides information about beach erosion at a specific location, while salinization is considered to be more problematic in that area, the information within the CCS can be seen as irrelevant.

2.6.3 Information

The information itself provided by the CCS is a very important category. It should be ensured that SLR Information is correct, non-biased and/or trustworthy (Cash & Belloy, 2020; Raaphorst et al., 2020). Besides that, the CCS could influence the perception or values of the involved stakeholders. This has to do with the risk perception or awareness of the stakeholders towards SLR (Hine et al., 2014). However, CCS should also take into account the values and perceptions the stakeholders have towards SLR (management), which refers to the legitimacy of the service. Legitimacy means whether the stakeholders think the outcomes of the CCS are desirable or appropriate within the (socially constructed) system of values and perceptions (Cash & Belloy, 2020).

There are many aspects or factors that could relate to the term 'information'. Within the CID framework, several examples are shown to which the category of information could refer to, which are physical, economic, social and political aspects. It should be noted that there could be more relevant types of information that could be placed in this category, which are not mentioned by the CID template as presented by the authors. Nevertheless, the CID framework still provides a broad range of possible aspects. When it comes to physical aspect, it will be about information regarding SLR and its consequences (higher flood risks, salinization etc.). However, SLR is a complex phenomenon and there is a lot of uncertainty about the extent to which sea levels will rise and how long it will take. Therefore, it could be hard to provide credible or legitimate information.

A second element which the information is related to is the economic dimension. During adaptation processes and especially in the planning and management phase, it is needed to have information about the costs and benefits of adaptation strategies (Cash & Belloy, 2020). However, it might be difficult to estimate what the costs and benefits of adaptation processes will be due to the fact that SLR is an uncertain event (Haasnoot et al., 2022).

The category of information also refers to the social dimension regarding the consequences of SLR. Impacts like higher flood risks, salinization or a change in the reachability of harbors could influence the demographics of certain coastal cities. For example, when the risk of flooding is becoming too high, stakeholders are probably not going to build properties anymore in this area. Another example is that houses built on wooden pile foundations could be affected by a higher level of salinization, caused by SLR. Because of this, SLR will have an influence on the social setting, as different types of foundations are needed to be used in order to prevent future damage.

Lastly, it could be that CCS should provide political information with regards to SLR. As figure 4 shows, the political aspects are often related to rules, laws and the way adaptation strategies can be stimulated (Lemos, Kirchhoff & Ramprasad, 2012). For example, a municipality could subsidize a project developer when the latter wants to raise the ground levels in order to lower future flood risks caused by SLR. Also, governments could introduce laws to make sure dykes need to meet certain levels of safety. However, when stakeholders responsible for SLR adaptation consider the information about the ways to implement or stimulate certain options to be wrong, a usability gap can be identified.

2.6.4 Visual format

The last element of the CID framework entails the visual format. This is about the way SLR information is projected or shown, which could be done by using maps, graphs, infographics, scenario's, reports etc. (Raaphorst et al., 2020). However, the way information is visualized should be appropriate in order to bring the message to the end-user in a usable way (Kerski, 2015; Hine et al., 2014). Thus, the visualization of the climate information should help end-users to get a better understanding about the complexity and difficulties of SLR impacts or management. When the format is not suitable for showing SLR information to the end-user, then it could influence the usability of the CCS (Raaphorst et al., 2020). For instance, stakeholders such as NGO's or businesses could be informed by images and storylines to get a better understanding about the impacts of SLR and possible adaptation measures. For example, when SLR information is provided in a report containing difficult terminologies , it is possible that this affect the usability of the CCS in a negative way (Raaphorst et al., 2020).

2.7 Additional communicative qualities: validity, readability and interactivity

Although the four elements of the CID framework (stakeholder, purpose, information, visual format) already provide a lot of insight in the possible factors that could influence the usability gaps within CCS, three additional communicative qualities should be distinguished: **validity, readability,** and **interactivity** Raaphorst et al., 2020; Raaphorst et al., 2018). According to Raaphorst et al. (2018), it is needed to add these dimensions, as a lack of critical research methods have been identified that support the importance of visual representations for communication between producers and end-users. ''landscape planners often use visual representations such as maps, graphs or videos for the creation of a future spatial layout'' (Raaphorst et al., 2018, p.163). By adding these three communicative qualities, a better understanding can be obtained of effective visual communication of CCS regarding SLR information.

validity refers to the extent to which a particular CCS reaches and affects the right/responsible audience, the purpose of the CCS is relevant considering with the policy cycle phase(s), the type of presented climate information is seen as credible or legitimate and to which the visual format is suitable for an accurate representation of the climate phenomenon (Raaphorst et al., 2020; Raaphorst et al., 2018). When it comes to readability, it is about whether the CCS is attuned with the visual language of the of its intended audience, the purpose of the CCS is transparent, the information depicted is clearly understandable, and whether it is clear how the visual format should be read (Raaphorst et al., 2018; Raaphorst et al., 2020). Finally, the interactivity means whether the CCS ''adheres to the viewing literacy of the audience, the possibilities for re-purposing the CCS and adding or adapting the information that is presented and modifying the visual mode in terms of scale or color'' (Raaphorst et al., 2018; Raaphorst et al., 2020). These qualities will be merged with CCS regarding SLR information. By doing so, twelve types of usability gaps arise from this which can be identified and explained by using this framework. Also, this information design is a useful tool to establish the feedback loops between the end-users and the producers of CCS (Raaphorst et al., 2020). This is shown in table 1.

Table 1: Analytical framework that describes 12 usability gaps for CCS (based on Raaphorst et al., 2020, p.6)

	Validity	Readability	Interactivity
Stakeholder	Is the desired action the responsibility of the targeted audience?	Does the visual language, and its possible connotations, of the CCS match the interpretive frames of the audience?	Is the visual literacy required for interpreting the CCS suitable for the targeted audience?
Purpose	Is the purpose of the CCS (understand, feel, act) suitable for the phase in the policy cycle?	Is the purpose of the CCS clear? (Otherwise users act before understanding the problem)	Can the CCS be repurposed by the user?
Information	Is the shown information regarding SLR correct/trustworthy?	Is it clear what information regarding SLR is presented in the CCS?	Can SLR information within the CCS be changed or modified?
Visual format	Does the visual mode enable an accurate representation of SLR?	Is the type of mode, and its way of reading, clear? (a story map requires a different viewing than a standard GIS map)	Can aspects of the mode (zoom level, color scheme etc.) be modified in the CCS?

2.8 Operationalization scheme

Based on the given theoretical framework, the following operationalization scheme can be set up. This has been done for the concepts of CCS, SLR adaptation performance/barriers, usability of SLR information and the factors influencing the usability gaps.

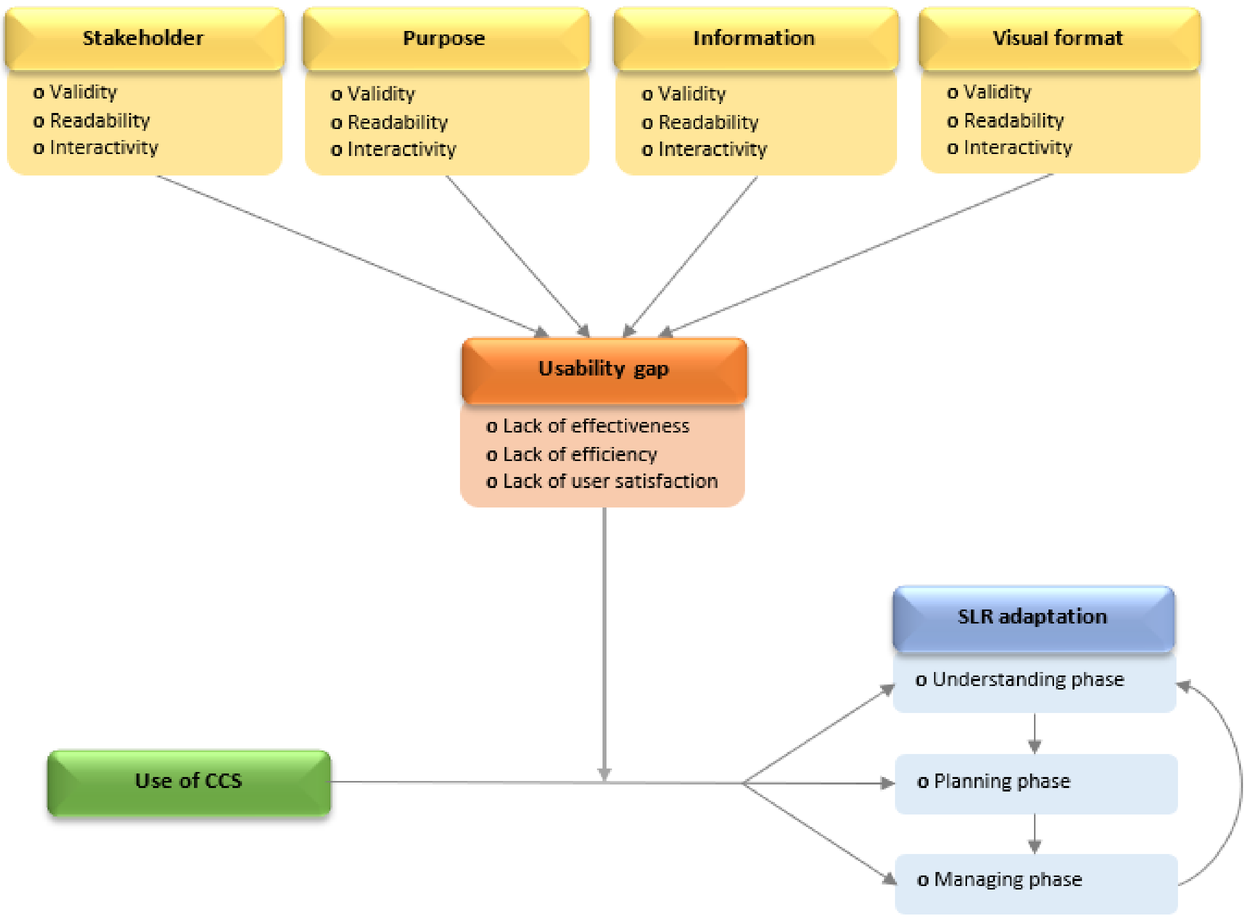
Table 2: *Operationalization*

Concept	Dimension	Indicator
CCS regarding SLR	Information services regarding SLR (impacts)	○ Map ○ Chart ○ Graph ○ Infographic ○ Scenario ○ Textual format ○ Report ○ Other
	Information services regarding SLR adaptation strategies	○ Map ○ Chart ○ Graph ○ Infographic ○ Scenario ○ Textual format ○ Report ○ Other
SLR adaptation performance/barriers	Understanding	○ Detecting problem ○ Gathering info ○ (Re)defining problem
	Planning	○ Developing options ○ Assessing options ○ Selecting options
	Managing	○ Implementing options ○ Monitoring option and environment ○ Evaluating options
Usability gap within CCS	Lack of effectiveness (CCS fail to meet information needs of responsible stakeholder in terms of effectiveness)	○ Goals cannot be completed ○ Information lacks accuracy
	Lack of efficiency (CCS fail to meet information needs of responsible stakeholder in terms of efficiency)	○ Too much time/money must be spent when using CCS
	Lack of user satisfaction (CCS fail to meet information needs of responsible stakeholder in terms of user satisfaction)	○ SLR information is not accessible ○ It is not easy to use CCS (e.g. lack of recognizable elements in CCS such as texts, images or interaction with system)
Factors explaining usability gap	Stakeholder	○ Targeting appropriate audience (*validity*) ○ Attuned visual language to mental frames of audience (*readability*) ○ Suitable visual literacy for stakeholder (*interactivity*)
	Purpose	○ Relevance of given information (validity) ○ Purpose is clear *(readability)* ○ *Can purpose be modified/changed (interactivity)*
	Information	○ Trustworthiness of information (validity) ○ Given type of information is clear *(readability)* ○ Information can be modified/changed *interactivity)*
	Visual format	○ Accurate representation by visual mode (*validity*) ○ How visual mode should be read is clear (*readability*) ○ Visual mode can be Modified/changed *(interactivity)*

2.9 Conceptual model

A conceptual model has been created, in which the interrelations between the main concepts are presented. First of all, it can be noted that the use of CCS may have a direct influence on SLR adaptation process. By providing SLR information through a CCS, users may utilize this information during the understanding phase (what is the problem?), the planning phase (what invention can be taken against the problem?) and the managing phase (how well is the problem solved by the intervention?). the possibility arises to understand the impacts of SLR, to plan adaptation solutions and to manage the implemented measures. However, various usability gaps could affect the extent to which CCS are being used for SLR adaptation. It could be that the CCS does not meet the information needs of the responsible stakeholder in terms of effectiveness, efficiency or user satisfaction, in order to achieve particular goals within a specified area. The identified usability gap can be influenced by various factors. The expectation is that usability gaps can be explained by using the CID framework (stakeholder, purpose, information, visual format), combined with the three mentioned communicative qualities of validity, readability and interactivity, proposed by Raaphorst et al. (2020). Within the conceptual model, it is shown that 12 potential factors could influence the usability gap in terms of effectiveness, efficiency or user satisfaction. Eventually, the usability gap influences the extent CCS is being used during the SLR adaptation process.

***Figure 8**: Conceptual model*



3. Methodology

In this chapter, the methodology of the research will be described. This will be done by explaining the research philosophy, the research strategy, the research design and the research method. After that, a description will be given about the way the data has been collected and analyzed. Lastly, it will be explained how the reliability and validity of this research have been guaranteed.

3.1 Research philosophy

Within this research, an attempt has been made to explain factors that influence the potential usability gaps within CCS regarding SLR information. It is therefore important to make clear which research philosophy has been used. A research philosophy can be described as ‘’a system of beliefs and assumptions about the development of knowledge’’ (Saunders Lewis & Thornhill, 2009). These beliefs and assumptions refer to the way the world is perceived, which is eventually lead to guidance in inquiry (Guba & Lincoln, 1994). It basically explains the way data about a certain phenomenon (e.g. factors that explain the usability gaps within CCS) should be gathered, analyzed and used. According to Burrel & Morgan (1979), the choice of the research philosophy depends on the research questions, research aim and the underlying philosophical foundation. In general, four main metaphysical beliefs (or paradigms) can be distinguished, which are positivism, post-positivism, critical theory and constructivism. These paradigms can also be explained by its ontology, epistemology and methodology (Guba & Lincoln, 1994; Creswell & Poth, 2017). According to Guba & Lincoln (1994), ontology comprises a continuum of realism (there is one world out there independent of us as humans) and relativism (there are multiple realities which are socially constructed). Epistemology, on the other hand, is concerned with way people come to know what they know. This is rather a continuum between objectivism, that assumes that there is a real world out there which is measurable, and constructivism which explains that all knowledge is socially constructed because there is no objective world to be measured. Finally, the methodology describes how data has been gathered and analyzed (Guba & Lincoln, 1994).

Within this research, the assumption is that the studied phenomenon (usability gaps of CCS regarding SLR information) cannot be observed from an objective viewpoint. To put it in the words of Guba and Lincoln (1994), usability gaps should rather be seen as a construction of the mind, as they are socially and experimentally based and dependent on the group of people who is holding this construction. This also means that this research fits within the research philosophy of constructivism, which has the assumption that certain are created by (a group of) humans, which shape the world. Besides that, constructivism addresses multiple realities, which are often contradicting each other (Creswell & Poth, 2017; Guba & Lincoln, 1994). There is no ‘exact’ truth, but the created realities should be seen as more or less informed or sophisticated (Guba & Lincoln, 1994). Therefore, the interpretation of the factors that influence the potential usability gaps can differ between groups of people and it is highly influenced by its social setting. For example, the existence of usability gaps and the factors which explain them may vary among coastal cities cross the world. Usability gaps could be caused by an unsuitable representation of SLR information or by uncertainty about the way the impacts of SLR are going to develop. Because of this, the usability gaps can be seen as socially constructed, which means that a constructivist view is suitable for answering the research question.

3.2 Research strategy

According to Van Thiel (2014), the research strategy plays a major role in the creation of the research design. The main research strategies are qualitative, quantitative or a mix of both (mixed methods) (Creswell, 2003). Qualitative research approach can be described as a holistic approach to develop a level of detail from high involvement in the actual experience (Williams, 2007). Quantitative research on the other hand involves a numeric or statistical approach to research design. Lastly, when it comes to mixed methods, both qualitative and quantitative approaches are being used, to draw from the strengths and minimize the weaknesses of the qualitative and quantitative research approaches (Williams, 2007). Within this research there has been made use of a qualitative approach in the form of a comparative case study. A qualitative approach is suitable for conducting this research, as it provides the possibility to understand the reasons why phenomena, such as factors influencing the usability gaps, are occurring (Creswell & Poth, 2017).

3.2.1 Comparative case study

A case study strategy has been used as it enables to understand complex real-life phenomena (Yin, 2003). ''Case studies are used to contribute to knowledge of individual, group, organizational, social, political, and related phenomena'' (Yin, 2003, p.1). Within this research, a comparative case study is used to get a better understanding about the interaction between policy makers and the CCS they make use of. According to Yin (2003), a comparative case study is more preferable than a single case study, as the findings of a single case study might be difficult to generalize (Yin, 2003). For example, SLR could have various impacts on the coastal cities and the way coastal cities deal with these hazards might be different as well. For the identification of the factors that explain the usability gaps within the used CCS, it is therefore more useful to investigate two cases.

The case study strategy is also in line with the constructivist view, as it enables to discover multiple perspectives that exist around the (potential) existing usability gaps, which is needed to come up with in-depth knowledge. In addition, an advantage of a case study strategy is that it enables data triangulation, which refers to the use of multiple methods or data sources in qualitative research to develop a comprehensive understanding of the studied phenomena (Patton, 1999). Data coming from a desk research, literature study, interviews or surveys can be compared or double checked, which is especially important for realizing internal validity and reliability (Creswell & Poth, 2017). The case study strategy is also in line with the constructivist view, as it enables to discover multiple perspectives that exist around the (potential) existing usability gaps, which are needed to come up with in-depth knowledge.

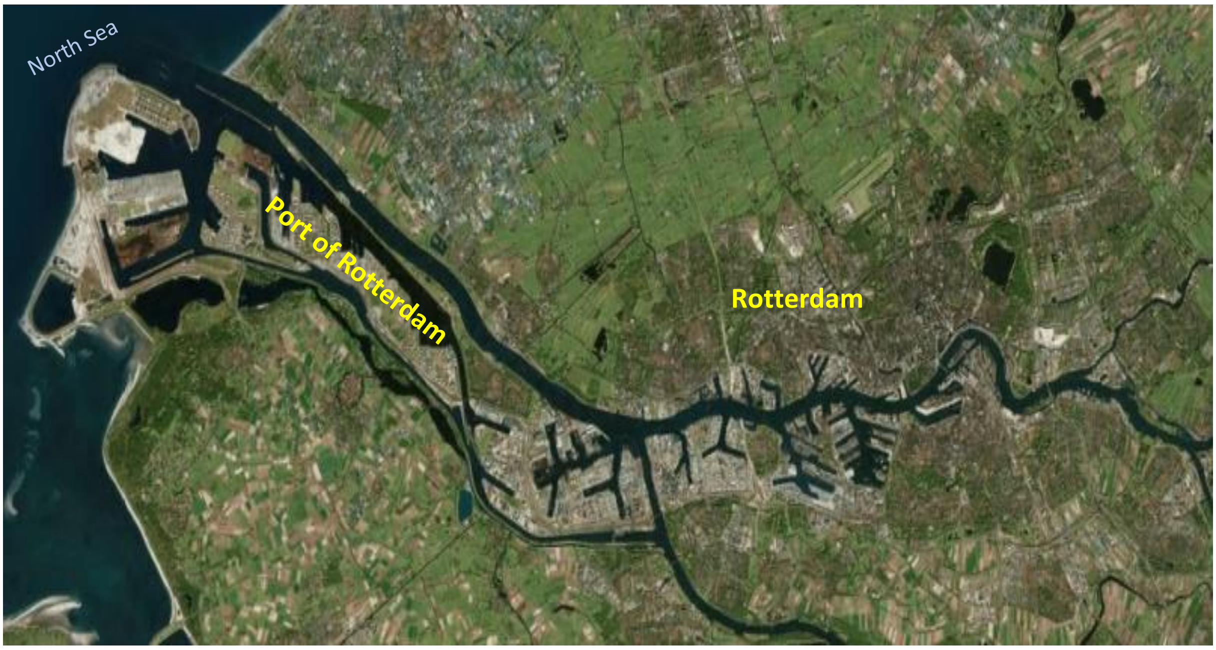
3.2.2 Case selection

It must be ensured that the selected cases represent a situation that is relevant for this research and the cases should therefore meet certain requirements. First of all, the selected cases should be relevant to the CoCliCo project, which means that the cases will be from a European country. Secondly, the selected case should be exposed in some way to the consequences of SLR, which are often cities that are located at the sea or in an estuary. Thirdly, certain CCS should be used within the coastal city to make informed decisions regarding SLR management.

1) Relevant to CoCliCo (European Case)
2) Exposed to sea level rise consequences
3) CCS are being used for informed decision-making processes

Rotterdam and Vlissingen meet all these criteria and are because of this selected as case studies. Rotterdam is located nearby the coast, with the harbor bordering the North Sea. This coastal city has ambitions to become a strong, attractive and climate resilient city, which is stated within documents like the Rotterdamse Adaptatie Strategie and the Rotterdams Weerwoord. Besides that, within the Nationaal Delta Program and the Rijnmond-Drechtsteden Delta Program, there are SLR strategies described for the realization of a resilient Rotterdam for the year of 2050 and 2100.

__Figure 9__: Location of Rotterdam (Viamichelin, n.d)



Vlissingen on the other hand, is located in the southwestern province of Zeeland, bordering the North Sea and the Westerschelde. Vlissingen also has the ambition to create a sustainable city, while simultaneously taking into account topics such as SLR and nature-based solutions within the urban area. This is stated in documents such as the Klimaatadaptatiestrategie Zeeland (KasZ). Besides that, Vlissingen participates in the European project of SARCC (Sustainable And Resilient Coastal Cities), in which governments, semi-governments and knowledge institutes are collaborating in order to adapt to challenges related to SLR in coastal cities for the year of 2100.

__Figure 10__: location of Vlissingen (Viamichelin, n.d)

Within the selected cases, the strategy is to investigate the CCS that are used within the selected cases during SLR adaptation process in order to find the usability gaps and to explain the factors that influence these gaps. Stakeholders responsible for SLR adaptation have been asked which CCS they make use of, to eventually go into further detail. The reason for this is that multiple CCS will be discussed in this way, which provide more insights about potential usability gaps. Besides that, it difficult to determine beforehand which CCS are being used by different policy makers.

3.2.3 Research approach

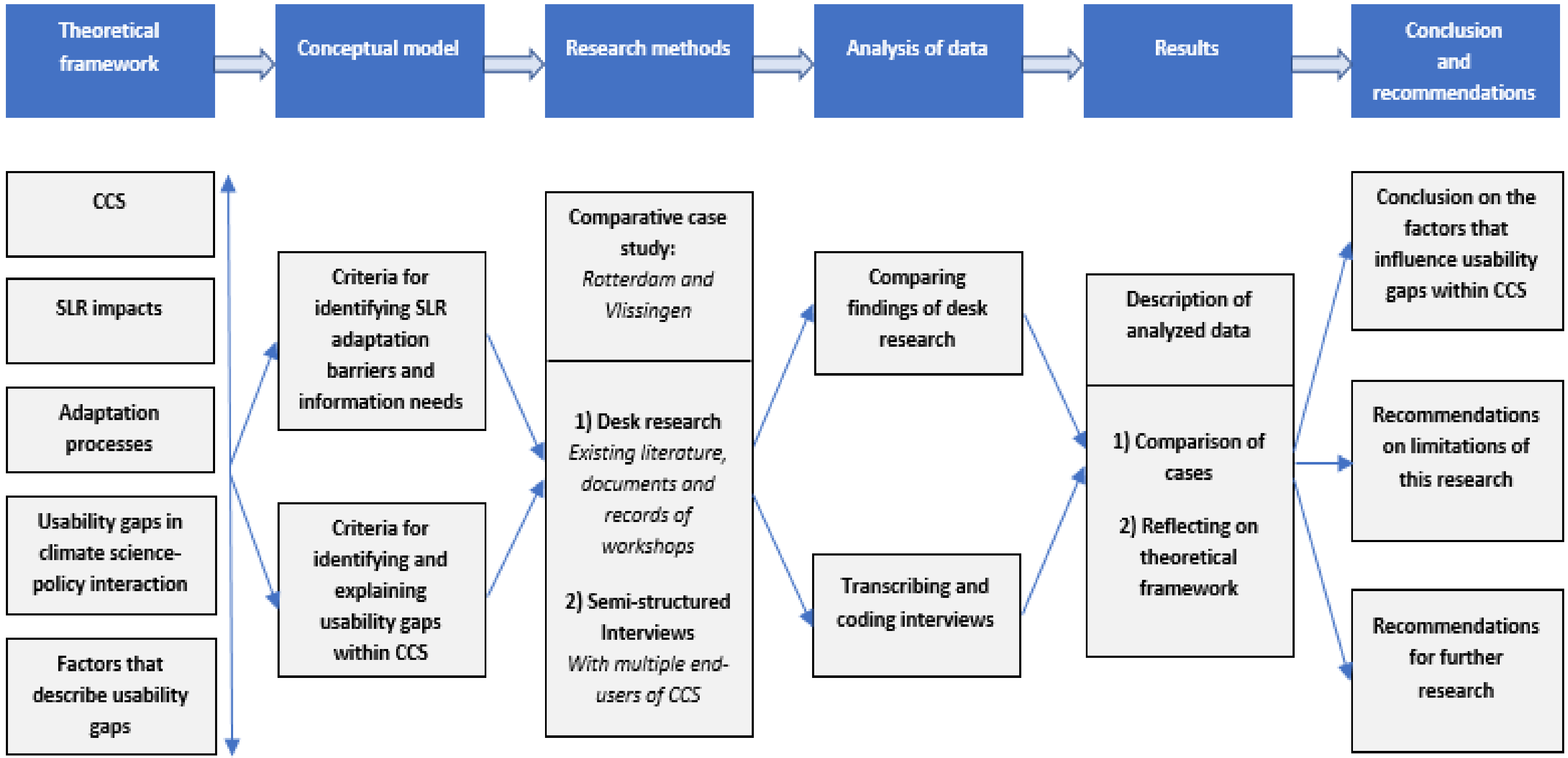
A distinction should be made between using an inductive or a deductive research approach. Inductive research starts with the research questions and the collection of data, which are then used to generate a hypothesis and a theory. By doing so, empirical generalizations will lead to new theories or insights (Saunders, Lewis & Thornhill, 2009). Inductive approaches are often used for analyzing qualitative data, as it provides a systematic set of procedures that can provide reliable and valid findings (Thomas, 2006). Deductive research approaches, on the other hand, usually begin with a theory-driven hypothesis which eventually guide the collection of data. This means that there might be an existing theory that could explain a certain phenomenon, which lead to a formulated hypothesis that can be tested by making use of a certain research strategy (Saunders, Lewis & Thornhill, 2009). Deductive approaches are often used during quantitative research, as it is useful to find causal relationships between concepts and variables (Saunders, Lewis & Thornhill, 2009). Both approaches, however, can be criticized. Inductive research, for instance, depend heavily on a substantial volume of empirical data that is needed to create valid generalizations of a certain phenomenon. Using an inductive approach can therefore lead to incorrect conclusions, even if all empirical data are accurate (Saunders, Lewis & Thornhill, 2009). When it comes to deductive research approaches, it is associated with a lack of critical or transparent selection of the theories used for conducting the research (Saunders, Lewis & Thornhill, 2009). When a wrong theory or premise is used, the conclusions of the research could be incorrect.

Since there are downsides to both approaches, it is common to use both inductive and deductive research approaches (Saunders, Lewis & Thornhill, 2009; Thomas, 2006). In this research, inductive and deductive approaches have been used as well. First, the inductive approach can be noticed as data about the factors influencing the usability gaps within CCS from local cases will be gathered, in order to develop a broader theory. Once a substantial amount of data had been collected, new theories about the factors influencing the usability gaps could be identified as patterns obtained from the case studies have been analyzed. This can be seen as a so called ‘’bottom-up strategy’’ in which the views and opinions of the participants are used to generate a broader theory (Saunders, Lewis & Thornhill, 2009). On the other hand, there is also a deductive dimension within this research, even though this research is essentially qualitative. A conceptual framework has been created and the main concepts have been operationalized which are used for collecting and analyzing the data. The latter included, for instance, an operationalization of the framework proposed by Moser & Ekstrom (2010) to identify adaptation barriers. Also, the analytical framework proposed by Raaphorst et al. (2020) have been used to describe the factors that influence the usability gaps within CCS regarding SLR information. This approach is a more top-down way of working, as the theory is leading to come up with valuable data (Saunders, Lewis & Thornhill, 2009).

3.2.4 Research design

Now the research strategy has been given, a research design can be set up. This gives an overview of the various steps of the research process and provides a framework for the collection of data (Bryman, 2012). This research consists of a literature study, a case study and a qualitative survey. When the first three phases had been done, the data was analyzed. After that, the results, the conclusion and recommendations have been written down. This process is shown in the research design in figure 11.

Figure 11: Research design



3.3 Research method, data collection and analysis

In order to come to a valuable conclusion on the main question, data triangulation is critical (Creswell & Poth, 2017). This means that multiple research methods are being used, so that data can be doublechecked. By doing so, it is possible to get a more holistic understanding on the factors influencing the usability gaps . Within this research, there has been made use of a desk research, semi-structured interviews and a qualitative survey. For each of these methods it will be explained how the data is going to be collected and how the data is going to be analyzed.

3.3.1 Desk research

The desk research has a fundamental role within this research, which consist of analyzing relevant existing scientific papers, (policy) documents and identifying available CCS. This way of collecting data depends on the literature study and is needed to gain in-depth information about the interaction between policy makers and CCS regarding SLR. The desk research has a vital role in identifying usability gaps and the factors that influence them. According to Sowers et al (2010), it is necessary to provide an overview of the sources and publication that have been used and in order to guarantee the validity and reliability of the research. First of all, documents of the CoCliCo platform are used as it provides information about usability gaps within CCS. Also, climate research programs such as the National Program Spatial Adaptation to Climate Change (ARK), Kennis Voor Klimaat (Knowledge for Climate, KVK) and het Nationaal Kennis- en Innovatieprogramma Water en Klimaat (National Water and Climate Knowledge and Innovation Program, NKWK) have been used to investigate the context of climate and SLR research in the Netherlands. Besides that, multiple CCS for the Netherlands have been identified on the web-portal Kennisportaal Klimaatadaptatie, to investigate which CCS are available.

Also, desk research is needed to understand the context of Rotterdam and Vlissingen. It serves as a way to determine the SLR consequences and to find out in which phase of the policy cycle (understanding, planning or management) Rotterdam and Vlissingen can be categorized in when it comes to SLR adaptation. Lastly, the information from the desk research have been compared to the findings from the case study, causing data triangulation. Regarding the case studies of Rotterdam and Vlissingen, policy documents that are published from 2009 onwards have been used. At this period of time, the Water Act has been introduced, which is still relevant when it comes to SLR management. Also, national policy documents and programs have been studied, such as the National Delta Program and the Kennisprogramma Zeespiegelstijging (SLR knowledge Program). For Rotterdam specifically, the used documents are the Voorkeursstrategie Rijnmond-Drechtsteden (preferred strategy), Rotterdams Weerwoord and the Adaptatiestrategie Waterveiligheid Haven van Rotterdam. Regarding Vlissingen, the Voorkeursstrategie Zuidwestelijke Delta (preferred strategy) and the Klimaatadaptatiestrategie Zeeland have been used.

***Table 3**: Overview of documents relevant for both cases*

Title	Author	Year	Type of document
Coastal Climate Core Services (CoCliCo). Research and innovation action	CoCliCo, Le Cozannet	n.d.	Report
National Program Spatial Adaptation to Climate Change (ARK)	N/A	2004-2011	National research program
Kennis voor Klimaat (Knowledge for Climate, KWK)	N/A	2007-2014	National research program
Nationaal Kennis- en innovatieprogramma Water en Klimaat (National Water and	N/A	2016 and onwards	National research program

Climate Knowledge and Innovation Program, NKWK)			
Kennisportaal klimaatadaptatie	N/A	N/A	Source for finding available (coastal) climate serivces
Climate Adaptation Services (CAS)	N/A	N/A	Source for finding available (coastal) climate serivces
Nationaal Deltaprogramma (National Program)	Ministerie van Infrastructuur en Waterstaat & Deltacommissaris	2022	National Policy Document/Program
Kennisprogramma Zeespiegelstijging (SLR knowledge Program)	Ministerie van Infrastructuur en Waterstaat & Deltacommissaris	2019	National Research program

***Table 4**: Overview of documents relevant for Rotterdam*

Title	Author	Year	Type of document
Voorkeursstrategie Rijnmond-Drechtsteden (Preferred Strategy)	Ministerie van Infrastructuur en Waterstaat & Deltacommissaris	2020	Regional policy document
Rotterdams Weerwoord Urgentiedocument	Gemeente Rotterdam	2019	Local policy document
Adaptatiestrategie Waterveiligheid Haven van Rotterdam	Port of Rotterdam	2022	Local policy document

***Table 5**: Overview of documents relevant for Vlissingen*

Title	Author	Year	Type of document
Voorkeursstrategie Zuidwestelijke Delta (Preferred Strategy)	Ministerie van Infrastructuur en Waterstaat & Deltacommissaris	2021	Regional policy document
Klimaatadaptatiestrategie Zeeland	Samenwerking Klimaatadaptatie Zeeland	2021	Local policy document

In addition, an overview is given in table 6 regarding the available CCS that can be used for SLR adaptation in the Netherlands. This information can be compared to the CCS that are being used in the case studies. As mentioned in the theoretical framework, a lot of programs have been established to create insights in climate change, SLR (impacts) and adaptation solutions in the Netherlands. SLR information coming from these programs have been integrated in various CCS. Regarding SLR information, the most important CCS are the KNMI climate scenarios and Delta Scenarios. These scenarios are a national translation of the global IPCC rapport, in which the impacts of global climate change on ecosystems, biodiversity and communicates are being shown (KNMI, n.d.).

Many other CCS have been created as well and a lot of them can be found on Kennisportaal Klimaatadaptatie (The Knowledge Portal). This is a pre-eminent source of information available for everyone involved in climate adaptation processes. Climate data on a national scale have been translated into multiplel)CS, which can also be applied for SLR adaptation. Examples for this are the Klimaateffectatlas, NAS Adaptatie tool, Klimaatschadeschatter or the Routekaart Risicodialoog. Other CS that can be used for SLR are, among other things, the Waterveiligheidsportaal, LIWO, Climate Resilient Cities Toolbox or overstroomik.nl. All these CS provide information based on national data.

Local CCS do exist as well, which often use data obtained from a local level. The municipality of Rotterdam, for instance, have created the Rotterdams Weerwoord in which the urgency of climate adaptation is addressed for multiple issues including SLR. Impacts of SLR are captured into charts and story maps, which are also represented into the Klimaatopgaven in Kaart. Besides that, to improve urban resilience towards SLR in Vlissingen, information can be obtained from Themakaarten Klimaat, which has been made available by the Province of Zeeland.

Table 6*: Available CCS in the Netherlands that can be used for SLR adaptation*

Available CCS	Goal CCS	Information	Visual representation
KNMI climate scenarios (based on IPCC report)	Show possible future scenarios / creating awareness	Trend, expectation and various scenarios on themes like temperature, rain, drought, or SLR (based on CO2 emissions), ahead of 2050 -2100	Scenario (including reports, key figures, tables and graphs)
Delta scenarios	Providing qualitative and quantitative data on climate, water systems, water consumption and use of land	Possible views on future climate change and socio-economic trends, ahead of 2050 -2100	Scenario / Report
Waterveiligheidsportaal	Showing actual status of safety primary flood defense system	Dike standards and assessment until the year of 2050	Interactive map
Landelijk Informatiesysteem Water & overstromingen (LIWO)	Showing inundation and flood risks / create awareness for professionals	Specialized knowledge on inundation and flood risks	Interactive map
Klimaateffectatlas	Showing local climate impacts / create awareness	Inundation, drought, heat, flood risks, based on national data	Interactive map
NAS Adaptatie tool	Creating own conceptual diagram regarding adaptation chances and risks of climate change for own work field or problem	Visual summary of (in)direct impacts of increasing heat, rain, drought and SLR	Interactive scheme
Climate Resilient Cities Toolbox	Exploring measures that increase water resilience of local area	Effectiveness and costs of adaptation measures	Interactive map
Klimaatschadeschatter	Showing estimation of costs of climate damage if nothing would be done against it	Costs of inundation, heat, drought and flooding	Interactive map
Overstroomik.nl	Showing water height in local areas and how to prepare for flood risks	Water height and footage of what to do if a flood event occurs	Interactive visual footage
Routekaart Risicodialoog	Help for preparing risk dialogue	Tips, tools or examples for preparing risk dialogue. Questions based on 4 categories: general, preparation, executing and finishing	Chart

Table 7*: Local CCS Rotterdam and Vlissingen based on desk research*

Local CCS Rotterdam & Vlissingen	Goal CCS	Information	Visual representation
Rotterdams Weerwoord	Showing local SLR impacts / inspiring people to adapt in Rotterdam	climate impacts, societal cost-benefits and possible subsidy schemes	Report / adaptation strategy
Klimaatopgaven in Kaart (Rotterdam)	Showing local SLR impacts / inspiring people to adapt in Rotterdam	Climate impacts, societal cost-benefits for issues like drought, heat, rain, inundation or flood risks	Charts, story map

Themakaarten Klimaat (Vlissingen)	Showing local SLR impacts in the Province of Zeeland	SLR impacts for issues like drought, heat, rain, inundation or flood risks	Interactive map

3.3.2 Semi-structured interviews

During this research, multiple semi-structured interviews have been conducted as well. It provides the opportunity to come up with in-depth data, coming from multiple perspectives (Creswell & Poth, 2017). Besides that, the interviews act as a double check on the literature study and the results of the desk research. When making use of interviews, it is possible to do this structured, unstructured or semi-structured. These different types of interviews all have different (dis)advantages.

When it comes to a structured interview, a strict interview guide is used in which the sequence of the questions must be followed in the exact same order as it is written down (Creswell & Poth, 2017). An advantage of this is that it generates a high degree of consistency, but there is also little room for respondents to bring up relevant information that deviates from the interview guide (Creswell & Poth, 2017). The opposite of a structured interview is an unstructured interview. The goal is to keep the conversation as broad as possible in order to collect as much information as possible (Creswell & Poth, 2017). An advantage of an unstructured interview is that respondents are completely free to talk about the topics he or she wants to talk about. However, a disadvantage is that unstructured interviews are hard to compare, as each respondent responded to different questions (Creswell & Poth, 2017).

Within this research, data is conducted by using semi-structured interviews. Within a semi-structured interview, only the most important questions are written down. But unlike structured interviews, it is possible by using semi-structured interviews to dive deeper into the answers of the respondent, which provides the opportunity to find more detailed or in-depth knowledge about the studied phenomenon (Creswell & Poth, 2017). It is also allowed to deviate from the interview guide itself in order to explore topics that are relevant to the respondent. Besides that, the order of the questions does not necessarily have to be followed. The interview guide is less strict than a structured interview, but more guiding than an unstructured interview (Creswell & Poth, 2017). Especially when it comes to complex issues such as the usability gaps within CCS, semi-structured interviews are effective for collecting data as it is needed to come up with in-depth data about the variables that influence these (potential) gaps (Yin, 2003). In order to do so, it is needed to have an interview guide which outlines the most important topics and questions of the research. Besides that, there are many stakeholders with different functions and responsibilities towards SLR management, which all could have divergent perspectives on the existence of the usability gaps and the factors that influence these gaps. Depending on what the respondent answers, the conversation could go into further detail, making a semi-structured interview most suitable (Yin, 2003). The interview guide can be found in appendix A.

End-users of CCS have been interviewed who are involved in realizing adaptation strategies for the city of Rotterdam and Vlissingen. Because of this, interviews have been arranged with several relevant organizations, such as Rijkswaterstaat (Directorate-General for Public Works and Water Management), the water board, the province, the municipality, and the port. Each of these actors need certain CS to support the adaptation process. However, it is important to keep in mind that every responsible stakeholder has its own set of rules and regulations, that could determine which CCS will be used.

For instance, **Rijkswaterstaat (RWS)** operates at a national level and could need CCS to protect coastal cities from flooding. RWS maintains the primary flood defense structures such as dikes, dams, weirs, or storm surge barriers (STOWA, n.d.). In addition, Rijkswaterstaat ensures that there is enough ground and surface water with a good water quality throughout the country. Besides that, Rijkswaterstaat has a responsibility to protect the coast and to create space for the rivers. **Water boards**, on the other hand**,** may use CCS in order to maintain the primary dikes, the water quality within their region, waterways and a sufficient fresh water supply. Besides that, water boards need to take care of natural areas in and nearby water areas (Rijksoverheid, n.d).

There are also responsibilities for governmental institutions. For example, **provinces** need to translate the national policy to policy on a more regional scale. In this case, spatial adaptation is needed when it comes to SLR (Nationaal Deltaprogramma, n.d.). Examples of this are to maintain the quality of ground water, reducing flood risks by implementing adaptive measures other than primary dikes, or by managing salinization within regional areas (Rijksoverheid, n.d.). The same tasks do more or less apply for **municipalities**. The difference is that municipalities implement adaptive measures on a local scale, while provinces do this on a regional scale. Municipalities need to take into account the national policy and regional policy, before making their own strategy (Rijksoverheid, n.d.; STOWA, n.d). When adapting spatially, municipalities need to combine SLR adaptation measures with other interests (such as business opportunities, nature, tourism, energy transition etc.). When it comes to SLR, municipalities are responsible for taking adaptive measures inside the dike area (if needed), to limit the risk of inundation, flooding, salinization, erosion etc. (STOWA, n.d). When it comes to areas outside of the dike area, however, municipalities do have a responsibility in facilitating strategies to prevent flood risks to occur (STOWA, n.d).

Furthermore, a relevant stakeholder could also be **ports,** which need adaptation solutions to, for example, limit flood risks or to stay accessible for shipping (Nationaal Deltaprogramma, n.d). Especially when it comes to areas outside the dikes, these stakeholders do have their own responsibility to protect themselves towards SLR impact.

In table 8 and 9, an overview of the interviews has been given for the case studies of Rotterdam and Vlissingen. An attempt to conduct an interview with someone working at the Province of Zuid-Holland has also been made, but during a phone call with an employee of this institute it became clear that this organization would give the same knowledge as Rijkswaterstaat and the water board Hollandse Delta, because they are all part of the Rijnmond-Drechtsteden Program. Because of this, the Province of Zuid Holland has not been interviewed. Also, an attempt has been made to speak with the North Sea Port of Vlissingen, but this has failed.

Table 8: *List of interviews Rotterdam*

Institution	Respondent	Way of interviewing	Date
Waterschap Hollandse Delta *(in text: water board HD)*	Henri van der Meijden	Teams-meeting	02-06-2022
Rijkswaterstaat West Nederland Zuid *(in text: RWS WNZ)*	Pim Neefjes	Teams-meeting	15-06-2022
Municipality of Rotterdam	Vera Konings	Teams-meeting	13-07-2022
Port of Rotterdam	Joost de Nooijer	Teams-meeting	23-08-2022

Table 9: List of interviews Vlissingen

Institution	Respondent	Way of interviewing	Date
Waterschap Scheldestromen *(In text: water board SDS)*	Samantha Van Schaik	Teams-meeting	20-01-2023
Rijkswaterstaat Zee en Delta *(In text: RWS ZD)*	Gert-Jan Liek	Teams-meeting	12-01-2023
Province of Zeeland*	Patrick Broekhuis	Teams-meeting	14-12-2022
Province of Zeeland*	Wendy van Meelis	Teams-meeting	14-12-2022
Municipality of Vlissingen	Els Jasperse	Teams-meeting	26-01-2023

* Respondents of Province of Zeeland were interviewed during same meeting

The opportunity was given to the respondents to do the interview face-to-face, by using a meeting via Teams or by phone calling. Eventually, all respondents have been interviewed during a Teams-meeting. Although Teams is a useful platform, it should be noted that there are some disadvantages to online interviews. For example, misunderstandings are more likely to occur due to an unstable internet connection. Also, it is a bit more difficult to notice body language than during a face-to-face interview. When conducting research, it is important to make sure that the interviewees are comfortable with providing answers and the storage of the data. During this research, it was needed to record the interviews in order to be able to transcribe the interview. Because of this, the interviewees had been asked for their permission about the recording of the interview. It had been made sure that audio fragments will only be submitted to the Radboud University, where it will be stored safely. Furthermore, it was also possible for the respondent to remain anonymous.

After the interviews were transcribed in Word, the transcripts have been coded in Atlas.ti. This is a software tool where statements of the interviewees can be coded (or labelled). When coding the interviews, one goes through the stages of open coding, axial coding and selective coding. Open coding can be seen as explorative, in which parts of the interview are identified which could be useful for the analysis. The labels are in this stage a bit ‘broad’, but more specific meaning will eventually be given to these concepts (Verschuren & Doorewaard, 2016). When the process of open coding has been done, one moves into the second stage of axial coding. During this phase, the labels are compared and merged, resulting in overarching and more specific codes (Saldaña, 2009). Lastly, the axial codes are transformed into selective codes during the third stage. The codes are merged again in order to come up with more general codes. Based on these selective codes, a theory can be built. By making use of this system of coding, large amount of texts can be analyzed in an easy way by linking statements to the theoretical framework (Saldaña, 2009). In appendix B, the codebook can be found that is used during this research.

3.4 Reliability and validity

According to Bryman (2008), the reliability and validity are the factors that determine the overall quality of the research. Reliability refers to the extent which the results of a study will can be reproduced under the same methodological circumstances (Bryman, 2012). It can also be seen as the consistency of the measures that have been done during the research. Within social sciences, it is difficult to provide the same results as before, as social circumstances are hard to freeze (Bryman, 2008). Therefore, the reliability of this research is guaranteed by using peer reviewed articles and many different documents that are used or created by all types of organizations such as governments, knowledge institutes, businesses or NGO’s. Besides that, the participants of the interviews have been selected carefully. The respondents need to have a relevant function or responsibility towards SLR management and they need to be an end-user of CCS.

Validity in qualitative research refers to the ‘appropriateness’ of the tools, processes, and data (Leung, 2015). ‘’Whether the research question is valid for the desired outcome, the choice of methodology is appropriate for answering the research question, the design is valid for the methodology, the sampling and data analysis is appropriate, and finally the results and conclusions are valid for the sample and context’’ (Leung, 2015, p.324). To put it differently, validity generally measures how correct the measures of the research are. Validity can be split up into internal and external validity (Bryman, 2012). Internal validity refers to the extent to which the conclusion of the research reflects reality (Bryman, 2012). It indicates whether the researcher measures what he or she wants to measure and whether this is done without any (researcher) biases or methodological errors. One of the main advantages of a qualitative research strategy is that the internal validity is relatively high (Creswell & Poth, 2017; Yin, 2003). Internal validity can be guaranteed by data triangulation, which means that different sources, theories and research methods have been used (Yin, 2013). Within this research, multiple documents have been investigated during the desk research and multiple semi-structured interviews have been conducted

A disadvantage of qualitative research is that the external validity cannot be guaranteed (Yin, 2013). External validity refers to whether the research can be generalized, or to put it differently, how well the outcome of a study can be expected to apply within other settings as well. Qualitative research is mostly useful for obtaining local and in-depth knowledge, but it is difficult to form a broader theory which can be applied on more cases around the world (Creswell & Poth, 2017). For instance, in-depth knowledge that is obtained about the usability gaps within CCS used in the cities of Rotterdam and Vlissingen may not apply for coastal cities in France or Germany. This is because every case is subject to different circumstances, which can also be linked to the constructivist view which explains that there are multiple existing realities. However, due to the multiple existing realities, the ‘truth’ is difficult to grasp (Guba & Lincoln, 1994).

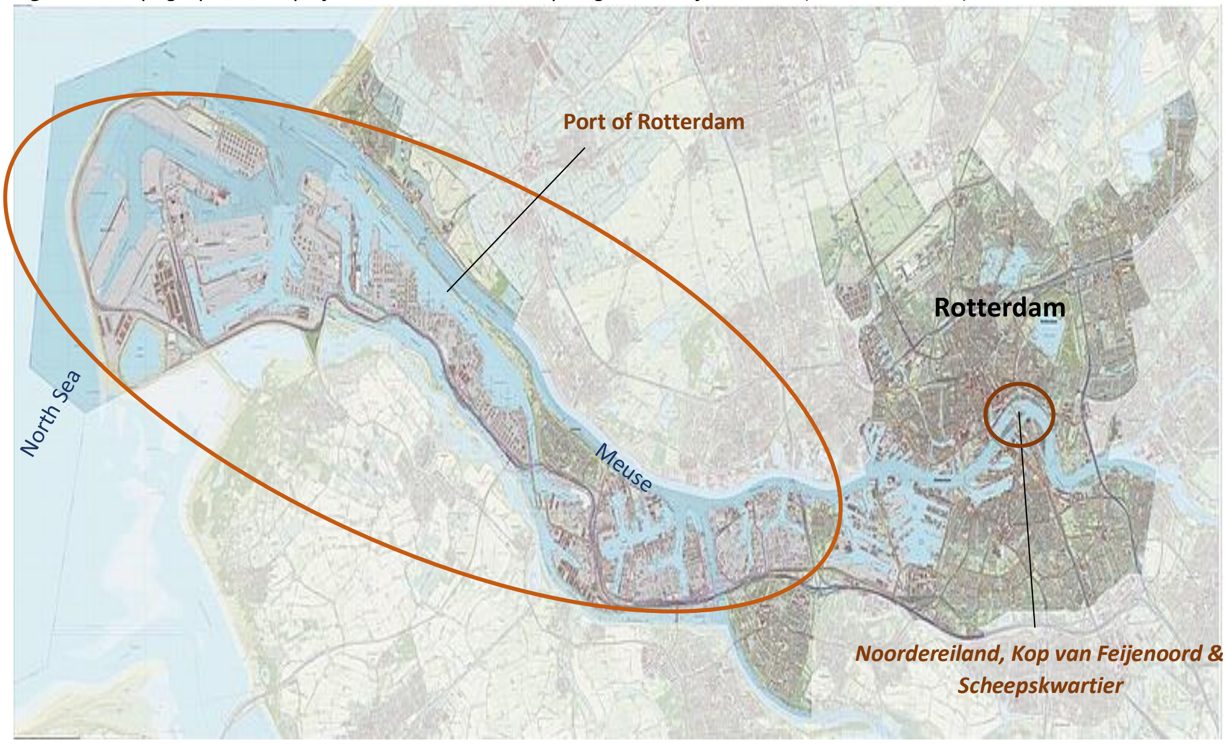
4. Results

In this chapter, the results that are obtained for the case studies of Rotterdam and Vlissingen will be shown. First of all, a description of the case Rotterdam will be given and its relation to SLR. When this is done, the CCS that are used during the SLR adaptation of Rotterdam will be shown, after which the information needs of the stakeholders will be given. These will be categorized into effectiveness, efficiency or user satisfaction to determine the usability of the used CCS. Eventually, the usability gaps can be identified and explained by the framework proposed by Raaphorst et al. (2020). After the results for Rotterdam have been revealed, the same procedure will apply for the case study of Vlissingen.

4.1 Case study of Rotterdam

Climate change is going to challenge the urban resilience of Rotterdam (Gemeente Rotterdam, 2022). Rotterdam is the second largest city in the Netherlands in terms of population (over a half million of inhabitants) and it is located in a low-lying area within a delta, containing many parts that are built below sea level (Delta program Rijnmond-Drechtsteden, n.d.). Throughout the years, Rotterdam has been evolved into an epicenter of international trade in Europe, which is mainly due to the central location of the city in relation to its hinterland. This provided the opportunity to develop into the largest harbor city in Europe when it comes to the transshipment of bulk goods (Port of Rotterdam, n.d). The port area extends over a length of 40 kilometers and it is counted as an important logistic and economic center (Port of Rotterdam, n.d.). Only the harbor is actually bordering the North Sea, while the other parts of Rotterdam are located more inland.

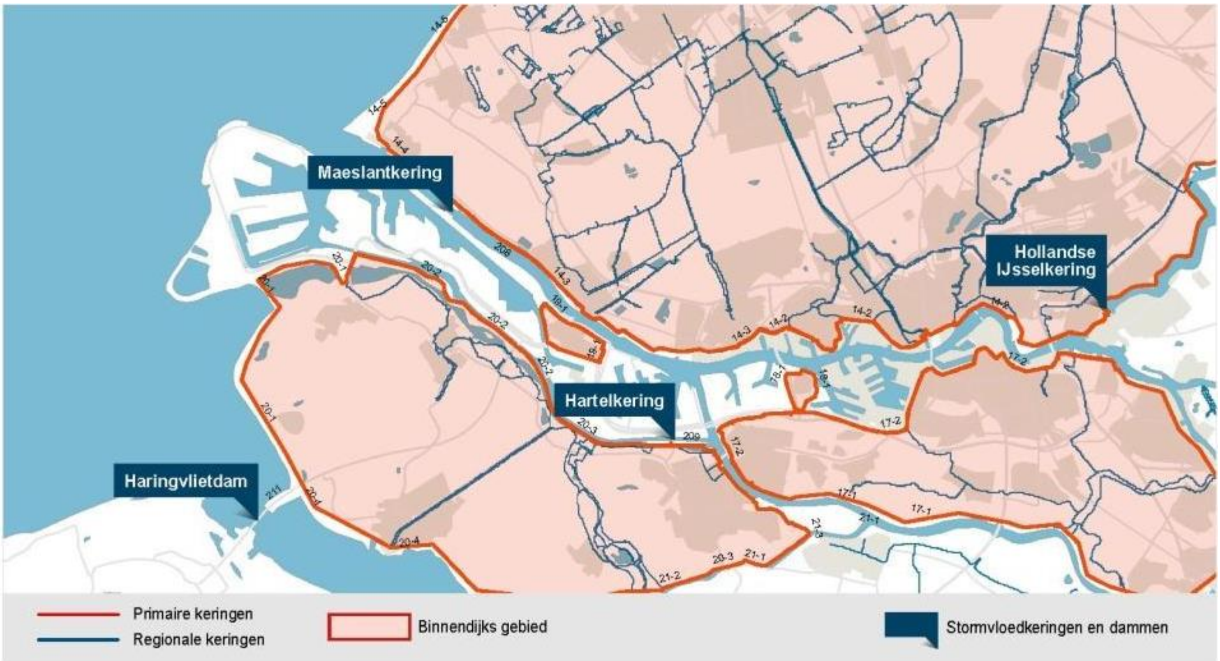
Figure 12: *Topographical map of Rotterdam based on open geo data of Kadaster (Van Aalst, 2022)*



Besides that, a combination of both the Rhine and Meuse are flowing through the Rotterdam which eventually flow into the North Sea. Although this provides many (economic) benefits for the city, it is also the reason why the more inland parts of Rotterdam are vulnerable for fluvial flooding. Especially the combination of high river discharges and storm surges coming from the North Sea could be risky for Rotterdam with regards to flooding. SLR could make this problem worse, as it is more likely that water from the North Sea will stream upwards the river Meuse (and Rhine) during a storm surge (Gemeente Rotterdam, 2019). Because of this, most parts of the city are protected by primary flood defense structures such as dikes and storm surges, with the exception of 'Noordereiland', 'Kop van Feijenoord', 'het Scheepskwartier' and the Port of Rotterdam (Municipality of Rotterdam, 2022).

According to all respondents, SLR mostly associated with fluvial flooding, the accessibility of the Port of Rotterdam and the function of the Maeslantkering. Right now, Rotterdam is structurally protected by primary defenses such as dikes and by storm surge barriers that are used during storm surges at sea, like the Maeslantkering, the Hartelkering and the Hollandse IJsselkering (see figure 9). Due to this, the chances of flooding within the inner dike areas are extremely low, but the primary flood defense systems will be challenged more often in the future due to SLR. Regarding fluvial flooding, the outer dike areas in Rotterdam are considered to be most vulnerable. A rise in sea levels will mean that fluvial flooding will occur more frequently in these areas, according to all respondents. However, RWS WNZ and the Port of Rotterdam argue that SLR impacts in the outer dike areas which are located behind the Maeslantkering (Noordereiland, Kop van Feijenoord, Scheepskwartier and parts of the Port) will be relatively mild in comparison to the areas located before the Maeslantkering (Maasvlakte and parts of the Europort).

***Figure 13**: Water barriers around Rotterdam (Gemeente Rotterdam, n.d.)*



A crucial aspect that has been mentioned in all interviews concerns the function of the Maeslantkering, which is a storm surge barrier. Rijkswaterstaat West-Nederland Zuid (RWS WNZ) argue that one of the most important choices in the long term is about a potential replacement of the Maeslantkering. ''Depending on the SLR scenario of what will unfold, the Maeslantkering could maybe last for another 50 years or 100 years. It might be wise to think about how you are going to replace it in 50 years'' (RWS WNZ, 2022). In addition, all respondents argued that SLR will have an impact on the accessibility of the Port, especially when considering to the extent to which the Maeslantkering should be closed per year. If this storm surge barrier is closed, it is not possible for ships to go through the Meuse towards the North Sea, leading to economic loss for the Port. A rise in sea levels will mean that this storm surge barrier should close more often, leading to even more economic disadvantages for the port. In the future, it might even be possible that the Maeslantkering should be replaced by a sea lock if sea levels rise too much (Water board HD, 2022).

Other than that, SLR is to some degree associated with salinization, rising ground water levels and the supply of fresh water. Salinization will get worse in the future due to SLR but it is still a question how big that problem is going to be for the city of Rotterdam. The ground will become a bit saltier, but within the city there is little agriculture, cattle breeding or nature (Municipality of Rotterdam, 2022).

4.2 CCS used during SLR adaptation process in Rotterdam

Now that the SLR impacts for Rotterdam have been discussed, the used CCS by the involved stakeholders will be shown. Also, it will be explained in which phase of the policy cycle these CCS are being used. When it comes to SLR adaptation, the water board HD makes use of the SLR scenarios of the KNMI and the Delta Scenarios. These scenarios are used to understand SLR effects on the current primary dike system around Rotterdam. Based on these scenarios, various adaptation strategies haven been developed which are explained within the Delta Program Rijnmond-Drechtsteden (part of the National Delta Program). Besides that, information from the SLR Knowledge Program is used to understand future SLR impacts and to plan SLR strategies. However, the Delta Program Rijnmond-Drechtsteden and the SLR Knowledge Program cannot be seen as CCS, considering the definition used in this research.

RWS WND uses the KNMI climate scenarios and the Delta scenarios as well. These scenarios are needed to understand what impact SLR will have on the primary flood defense structures, referring to possible future dike reinforcements or the function of the Maeslantkering. Based on these scenarios, a preferred strategy can be created which is explained in the regional Delta Program Rijnmond-Drechtsteden, as a part of the National Delta Program. Also, information from the SLR Program is used to understand SLR consequences and to plan SLR strategies. The latter two are, however, not seen as CCS.

According to the municipality of Rotterdam, national sources on SLR information are considered important for understanding the return period of high levels of water. This information serves as a base to understand what the impacts of SLR will be on Rotterdam. However, the municipality does not have the expertise to calculate the return period. Instead, the municipality uses the given results for Rotterdam. Also, the municipality mentioned that the Klimaateffectatlas and LIWO (National Information System Water and Flooding) are used to identify the areas that are vulnerable for (future) flood risks. Besides that, the municipality of Rotterdam has created their own CS which can be used for SLR adaptation, referring to the Rotterdams Weerwoord and the Klimaatopgaven in Kaart in which SLR impacts are shown in several charts, combined with a storyline. Information within Rotterdams Weerwoord and Klimaatopgaven in Kaart are also used to communicate SLR risks and strategies towards citizens and project developers.

Regarding the Port of Rotterdam, the KNMI scenarios serve as a base for understanding SLR impacts. The information provided by the KNMI scenarios is needed to understand the extent of which sea level will rise and what the return period will be of high-water levels. Besides that, the Port of Rotterdam has created its own created CCS in which the KNMI scenarios are translated into local adaptation strategies and decision support tools. The Port has made its own adaptation strategies for each area of the Port (Adaptation Strategy Water Safety Port van Rotterdam). These adaptation strategies can be seen as CCS as well**.** Other than that, the Port has created the CCS “Maatregelen Waterveiligheid”, in which the Port could communicate various feasible adaptation strategies towards the users of the port (such as businesses). Also, on the website of the Port of Rotterdam, an interactive chart can be found (“Kaarten Waterveiligheid”), which show a detailed understanding of water depths and the chance of flooding within the Port. Lastly, the Port of Rotterdam even creates charts for the Klimaateffectatlas. The CCS that have been created by the Port of Rotterdam functions also as a communication tool towards the users/clients of the Port.

Table 10*: Overview of CCS used in Rotterdam for SLR adaptation*

CCS	Used by	Goal CCS	Information	Visual representation
KNMI climate scenarios (Based on IPCC report)	Water board HD RWS WNZ Municipality of Rotterdam Port of Rotterdam	Show possible national future scenarios / creating awareness	Trend, expectation and various scenarios based on CO2 emissions ahead of 2050 - 2100	Scenario (including reports, key figures, tables and graphs)
Delta Scenarios (Based on IPCC report)	Water board HD RWS WNZ	Providing qualitative and quantitative data on climate, water systems, water consumption and use of land	Possible views on future climate change and socio-economic trends, ahead of 2050 -2100	Scenario (graphs, tables, storylines and charts)
Rotterdams Weerwoord	Municipality of Rotterdam	Showing local SLR impacts / inspiring people to adapt	Societal cost-benefits SLR impacts Possible subsidy schemes	Report / adaptation strategy
Klimaatopgaven in Kaart (part of Rotterdams Weerwoord)	Municipality of Rotterdam	Showing local SLR impacts / inspiring people to adapt in Rotterdam	Climate impacts, societal cost-benefits for issues like drought, heat, rain, inundation or flood risks	Charts, story map
Klimaateffectatlas	Municipality of Rotterdam	Showing national climate impacts	Vulnerable areas for issues like drought, heat, rain, inundation or flooding	Interactive chart
LIWO	Municipality of Rotterdam	Showing flood risks / creating awareness	Water depth when flooding vulnerable areas	Chart
Maatregelen Waterveiligheid Port	Port of Rotterdam	Showing local SLR impacts / showing adaptation strategies	Water depth when flooding vulnerable areas Adaptation possibilities, subsidy schemes	Schematic overview of adaptation strategies with visuals
Kaarten Waterveiligheid	Port of Rotterdam	Creating awareness about risks regarding water safety	Showing impacts flooding in Port and potential adaptation strategies	Interactive map
Adaptation strategies Port	Port of Rotterdam	Communicating feasible adaptation strategies for (future) water safety	Possible local adaptation strategies for stakeholders at Port	Report / adaptation strategy

4.3 SLR information needs and the usability of CCS

Within this segment, the goal is to describe the information needs of each stakeholder that has a responsibility within the case Rotterdam. When this is done, the information needs can be categorized into effectiveness, efficiency and/or user satisfaction.

4.3.1 Water board Hollandse Delta

When it comes to the SLR information needs, the water board HD referred to information needs within the usability category of **effectiveness** (completeness of goals in accurate way). During the understanding phase, the water board should be able to find datasets (robust information) about how much sea levels will rise in the future and to what extent it will create pressure on the current primary flood defense system around Rotterdam. To be more precise, SLR data are needed to calculate whether the current dikes are still sufficient for the protection against future SLR. When a dike does not meet the requirements of the Water Act, it can become more difficult to manage it towards the future, especially considering SLR. In relation to that, it will also have consequences for the 'dijklegger', 'dijkreserveringszones' or 'profiel vrije ruimte'. In English, this refers to the space that is reserved for potential dike reinforcements. However, there are different interests within the use of space within Rotterdam (e.g. energy transition, biodiversity and housing), which means that more and more attention is being paid to the flood defense system.

Information needs in the category **user satisfaction** (accessibility, ease of use) are also mentioned. Information should provide guidance with regards to the level of uncertainty that is coming along with the theme of SLR, which can be referred to the ease of use for determining which scenario is likely to happen. The water board HD need to have reliable information about possible future scenarios. Although it is not possible to look into the future, it is important to understand the likelihood of which a scenario could happen. This information is needed to have insights in the socio-economic developments in Rotterdam in relation to SLR.

4.3.2 Rijkswaterstaat West-Nederland Zuid

Regarding RWS WNZ, information needs are mainly found in the category of **effectiveness**. Data sets (robust information) are needed about when and the extent to which SLR will rise (including return period). This is needed to understand the impacts of SLR on the primary flood defense structures, fresh water supply and the port accessibility. According to RWS WNZ, it is possible that (parts of the) the current flood protection system will no longer be sufficient if circumstances change due to SLR. For instance, when high water levels reach Rotterdam, the Maeslantkering could be closed to prevent hazardous situations to happen. If the sea level rises in the future, this barrier could be insufficient when managing high levels of water.

Furthermore, information needs in the category **user satisfaction** are mentioned as well. RWS WNZ need to have access to information for managing the uncertainties that are coming along with SLR. However, when and the extent to which sea levels are rising is complex and uncertain, meaning that SLR information should provide a 'grip' or 'starting points' to manage these uncertainties. It is important to understand the likelihood of the scenarios that could happen, especially when considering the costs and bates of different kinds of adaptation strategies. Therefore, a component of ease of use is identified.

4.3.2 Municipality of Rotterdam

SLR information needs of the municipality of Rotterdam have been identified in the category of **effectiveness**. There is a need for in-depth information on reducing future flood risks in these areas, especially in the outer dike areas (Noordereiland, Kop van Feijenoord and Scheepskwartier). Besides that, the municipality has interest in the use of space (housing, energy transition) nearby the dikes. For instance, if the municipality wants to build houses in an outer dike area, these should be built for the coming 100 years. To stay resilient, the municipality needs to know how much the ground should be raised or what adaptive measures could be taken in the spatial area.

Besides that, attention should be paid to the **user satisfaction** of the given information. For instance, SLR is linked to a high level of uncertainty and it could be difficult to predict how much the ground levels need to be raised and how expensive this will be. This makes it also more difficult for the municipality to address the potential financial impacts. ''It could be unnecessary to raise the ground levels now if a sea lock will be built in the upcoming 30 or 40 years as a replacement of the Maeslantkering'' (Municipality of Rotterdam, 2022). Besides that, the challenge for the municipality is to create awareness by translating complex information about SLR to project developers or citizens. The municipality of Rotterdam stated that project developers need to take into account many other themes as well and SLR is just one of them. For these kinds of stakeholders, information should be easy to understand and directly applicable, which can be seen as 'low threshold' information. Citizens or project developers will definitively not use tools or models to calculate exactly at what height their house should be built to reduce flood risks in the most optimal way. Another aspect mentioned by the municipality of Rotterdam refers to the reliability of information. Due to the uncertainty about when and to what extent sea levels will rise, it is desirable to have SLR information which contain the same results regarding a particular issue.

4.3.4 Port of Rotterdam

Regarding the port of Rotterdam, information needs appear in the category of **effectiveness**. The port is located outside the dikes, meaning that a sustainable spatial planning is important. Every part of the Port has its own adaptation strategy and to adapt effectively, in-depth information is needed about the vulnerable areas within the port regarding flood risks (Port of Rotterdam, 2022). One of the reasons for this is that adaptation in areas that outer dike areas need to be approached differently. Also, there are differences between the areas that are located in front of the Maeslantkering (Maasvlakte and parts of Europort) and the areas that are behind the Maeslantkering (parts of Europort, Botlek, Vondelingenplaat, Merwe-Vierhavens and Waal-Eemhaven). Besides that, information on feasible adaptation strategies should be provided to the users of the port.

Information needs can be found in the category of **user satisfaction** as well. First of all, the CCS should provide insights in the costs and benefits of adaptation strategies in relation to the potential risk reduction. It is needed to provide guidance to this, as it is difficult to estimate when local adaptations strategies will be sufficient. Besides that, the port is responsible for its own water safety and, because of this, it is mentioned that there is a need to have 'control' over what is being communicated towards their clients. ''As a port company, we are the area director and we also have a responsibility in this respect when it comes to communication. In that sense, you do not want other sources to exist containing misleading or incorrect information (Port of Rotterdam, 2022)''. Also, the port stated the importance of translating complex climate information to more understandable information that can be used for the communication to the users of the port. By doing so, users of the port can be inspired to create feasible adaptation strategies.

4.3.5 Usability (gaps): are information needs met by the CCS?

Now the SLR information needs of the involved stakeholders for the city of Rotterdam are explained, it is possible to compare these needs with the actual usability of the used CCS. According to the water board HD**,** SLR is highly uncertain and a slow process, but the KNMI scenarios provide insights and tools for adaptation. ''Within our institute, people do have the skills and knowledge to transform this information in graphs and tables into something we can work with. These scenarios are there useful to get a grip on future SLR'' (water board HD, 2022). However, managing the uncertainties of SLR remain difficult, which could lead to socio-economic uncertainties. In that sense, a slight usability gap may be present in the category of user satisfaction.

RWS WNZ reacted surprised at the assumption that the KNMI scenarios or Delta Scenarios would not be usable. These scenarios are seen as an important starting point for SLR adaptation strategies. ''We basically use the outcomes of these scenarios and then we make use of our own models to see what the SLR effects will be and what these effects will have on our flood defence system or fresh water supply. I actually think thay the information provided to us is already structured and that we benefit from that when creating an adaptation or preferred strategy'' (RWS WNZ, 2022). On the contrary, it was admitted that the KNMI scenarios are 'just' scenarios and not everyone believes every extreme or less extreme scenario. Moreover, policy should be based on these scenarios, which could lead to socio-economic uncertainties. The latter implies a slight usability gap.

The municipality of Rotterdam replied that the KNMI scenarios are leading for understanding SLR impacts. However, these scenarios are not usable for making local policies or for the commmunication towards projects developers or inhabitants or to find accurate local impacts. In addition, these CCS do not contain guidance in relation to the costs and benefits of possible adaptation strategies. It was also argued that CCS based on national data (Klimaateffectatlas or LIWO) do not provide in-depth information. The Rotterdams Weerwoord and Klimaatopgaven in Kaart do also contain a simplification of SLR information for the communication towards citizens and project developers. Lastly, it was mentioned that not all CCS provide the same information regarding a particular issue. For the municipality, clear usability gaps can be identified.

The Port of Rottedam also states that the KNMI scenarios serves as a base for understanding SLR impacts on the ports and the return periods for high levels of water. However, CCS such as the KNMI scenarios or the Klimaateffectatlas do not provide in-depth information on local flood risks in the port area. Therefore, the port made their own CCS that support creating adaptation strateiges. In addition, CCS should be useful for creating a cost and bate analysis regarding the adaptation strategies in the port area. However, it is hard to calculate the risk reduction of local adaptation strategies, meaning that a lot of data is needed to understand whether a particular strategy is sufficient. Also, SLR information that is communicated towards port-users should be reliable (Port of Rotterdam, 2022). However, it was mentioned that various CCS provide different information regarding the same issue. Therefore, clear usability gaps arise within the CCS used by the port of Rotterdam.

In table 11 and 12, an overview is given about the SLR information needs during the understanding and planning phase (management phase was not recalled by the respondents). In the third row, the green color means that there is no usability gap, the yellow color implies a slight usability gap and the red color suggests that there is a clear usability gap.

***Table 11**: Usability (gaps) CCS used in Rotterdam during the understanding phase*

SLR Information needs during the understanding phase mentioned by the respondents	Recalled by	Are information needs met by the CCS? (Yes / Somewhat / No)	Usability (gap) category
Information on when and to what the extent sea levels will rise (including return period)	Water board HD	KNMI and Delta scenarios provide insights on when and to what extent SLR could rise	Effectiveness
	RWS WNZ	KNMI and Delta scenarios provide insights on when and to what extent SLR could rise	Effectiveness
Datasets/robust Information on SLR impacts	Water board HD	KNMI and Delta scenarios provide data sets/robust information that can be plotted in software tools. Eventually, the SLR impacts can be calculated on current preferred strategy (in relation to hydraulic boundaries of flood defense system)	Effectiveness
	RWS WNZ	KNMI and Delta scenarios provide data sets/robust information that can be plotted in	Effectiveness

		software tools. Eventually, the SLR impacts can be calculated on current preferred strategy (in relation to hydraulic boundaries of flood defense system, fresh water supply or port accessibility)	
In-depth data on local SLR impacts	Municipality of Rotterdam	Rotterdams Weerwoord and Klimaatopgaven in Kaart provide charts with high resolution on local SLR impacts	Effectiveness
		CCS based on nationally obtained data (e.g. Klimaateffectatlas or LIWO) do not provide in-depth SLR information for local areas.	Effectiveness
		Various CCS provide different SLR information and results regarding the same issue.	User satisfaction
	Port of Rotterdam	Rotterdams Weerwoord and Kaarten Waterveiligheid contain information with high resolution on local SLR impacts in port area	Effectiveness
		CCS based on nationally obtained data (e.g. Klimaateffectatlas) do not provide in-depth SLR information for port area	Effectiveness
		Various CCS provide different SLR information and results regarding the same issue.	User satisfaction
Visualization of SLR impacts / ease of use	Municipality of Rotterdam	Rotterdams Weerwoord and Klimaatopgaven in Kaart provide a textual format and charts that visualize insights in SLR risks	User satisfaction
		KNMI scenarios are too complex for communicating SLR information	User satisfaction
	Port of Rotterdam	Adaptation Strategies of Port and Kaarten Waterveiligheid provide simple insights in SLR risks in the form of reports and interactive maps	User satisfaction
		KNMI scenarios are too complex for communicating SLR information	User satisfaction

***Table 12**: Usability (gaps) CCS used in Rotterdam during the planning phase*

SLR Information needs during planning phase mentioned by the respondents	Recalled by	Are information needs met by the CCS? (Yes / Somewhat / No)	Usability (gap) category
Guidance in assessing/planning strategies	Water board HD	KNMI scenarios provide insights in future SLR, but there are still uncertainties. This leads to issues when planning adaptation measures or other socio-economic developments	User satisfaction
	RWS WNZ	Not everyone agrees on which scenario should be followed when adapting to SLR. Lead to uncertainties in socio-economic developments in relation to SLR	User satisfaction
	Municipality of Rotterdam	It is difficult to estimate when over- or under-investments will be made considering SLR scenarios	User satisfaction
	Port of Rotterdam	Costs and benefit analysis can be done by using the CCS. However, calculating risk reduction of local adaptation strategies can be difficult as a lot of data is needed.	User satisfaction
Visualization of possible adaptation strategies / ease of use	Municipality of Rotterdam	Local decision-takers need starting points which are directly for creating adaptation strategies. These are provided in various CCS such as Klimaatopgaven in Kaart	User satisfaction
	Port of Rotterdam	Maatregelen Waterveiligheid provide feasible local adaptation solutions in an interactive scheme	User satisfaction

4.4 Factors influencing usability gaps within CCS used in Rotterdam

Within this segment, it will be explained which factors influence the found usability gaps. This will be done by providing an overview for each component of the Climate Information Design (stakeholder, purpose, information and visual format. For each factor, the aspect of validity, readability and interactivity will be discussed.

4.4.1 Stakeholder validity

The first element within the CID framework refers to the stakeholders that are using a particular CCS. Stakeholder validity refers to whether the desired action is the responsibility of the targeted audience. To put it differently, it is important that the CCS targets the right/responsible audience. All respondents were clearly aware of the fact that stakeholders need different kinds of information depending on their responsibility. That is why many different CCS are required to fulfill all information needs. Information from the KNMI scenarios may be attuned for the water board HD and RWS WNZ, but not (entirely) for the municipality or the port.

For instance, the municipality of Rotterdam argues that the KNMI scenarios are needed to understand the potential risk of SLR. However, these scenarios are not usable for creating adaptation solutions in the port area. Regarding spatial adaptation, the municipality and the port make use of different CCS as these provide more relevant data for local decision making (even though the KNMI scenarios serve as a base for understanding the return period of high levels of water). Due to the fact that different CCS are available for all kinds of responsibilities, no usability gap arises in this segment.

4.4.2 Stakeholder readability

Stakeholder readability comes down to whether the visual language, and its possible connotations, of the CCS match the interpretive frames of the audience. According to all respondents, it is essential to know who the target audience is. SLR is a complex theme to understand, which means that the visual language within the CCS should be attuned to different audiences. According to the water board HD and RWS WNZ, information provided by the KNMI scenarios can be understood easily, as it is their profession. ''As a technician, I can easily make use of the graphs or tables coming from the IPCC or the KNMI'' (RWS WNZ, 2022).

On the contrary, the municipality of Rotterdam states that the given KMMI scenarios are not suitable for policy making, as municipalities do not have the needed knowledge to work with these scenarios. The municipality and the port both argue that complex SLR information about the impacts and possible strategies needs to be visualized in an easy way (by creating storylines or charts), especially for communicating SLR risks towards project developers and inhabitants. For example, a specified height level relative to NAP is usable for project developers, because it is immediately clear how high a building should be built (in Dutch: uitgiftenpeil). ''If everyone knows those height levels for building houses or other projects, there will be less discussion'' (Municipality of Rotterdam, 2022).

The Port of Rotterdam adds to this that information for the creation of adaptation strategies should be like 'low hanging fruits', to make sure people understand simple adaptation strategies to reduces SLR risks. For the municipality and the port, it is therefore preferable to make use of their own CCS. Eventually, usability gaps can be found for the municipality and the port.

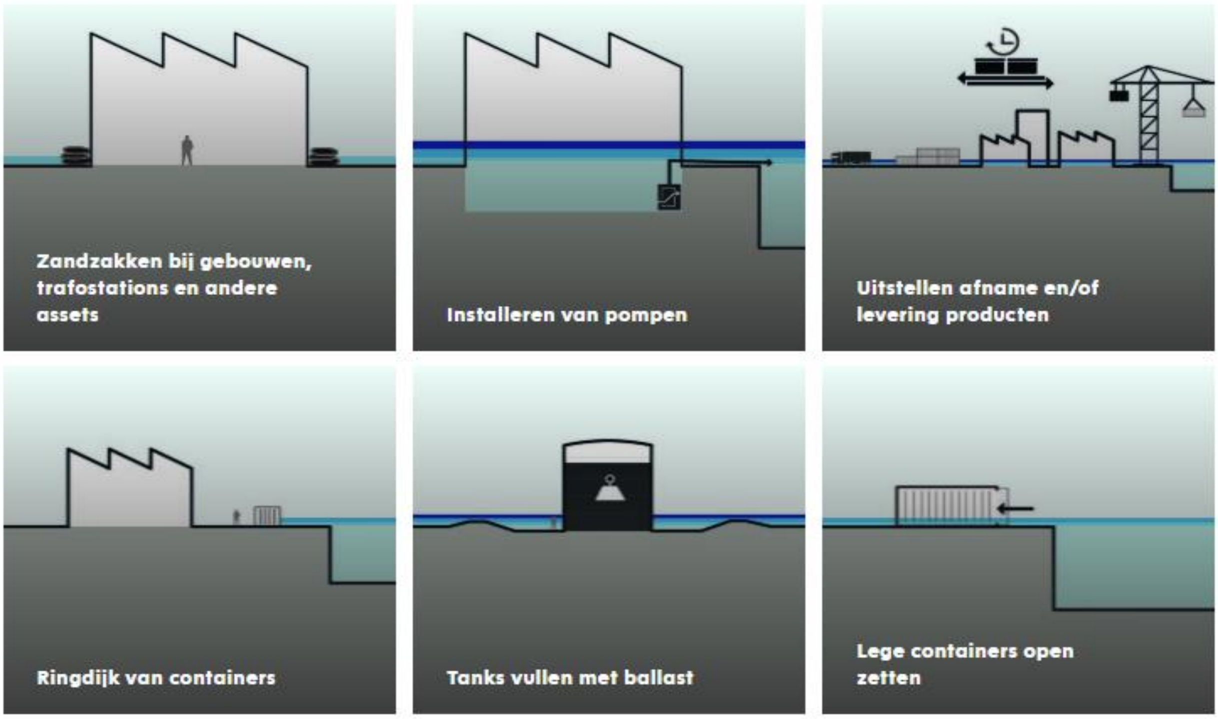
4.4.3 Stakeholder interactivity

Within the category, it will be discussed whether the visual literacy required for interpreting the CCS is suitable for the targeted audience. It is about the complexity of data and its relation to the interactivity with the visual literacy. Some CCS may have interactive functions, but these need to be attuned to the interpretive frames of the audience. The water board HD and RWS WNZ argue that there is not per se a need for interactive functions with the used information, as they have the expertise to work with this data.

RWS WNZ does however provide a suggestion to make a chart in which it is possible to see what the economic consequences will be of certain decisions, depending on the extent sea levels will rise. ‘’If the targeted group is extended to all inhabitants of the Netherlands, it could be helpful to interact with the CCS’’ (RWS WNZ, 2022). This is also mentioned by the municipality of Rotterdam, which refers to simple ways of visualizations for projects developers or inhabitants. An example of this is overstroomik.nl in which users can see potential flood risks in a partical are, while interacting with the CCS.

The Port of Rotterdam argues that interactive visualization is important for their port users, not only to communicate the risks in a simple way, but also to visualize simple adaptation strategies for user to interact with. The port made even for this their own CCS (see figure 14). Not all CCS provide these visualizations, but there are CCS availale that visualize the complexity of SLR information with interactive functions. Therefore, there is no usability gap found in this segment.

Figure 14*: Example of Maatregelen Waterveiligheid, CCS made by Port of Rotterdam (Port of Rotterdam, n.d)*

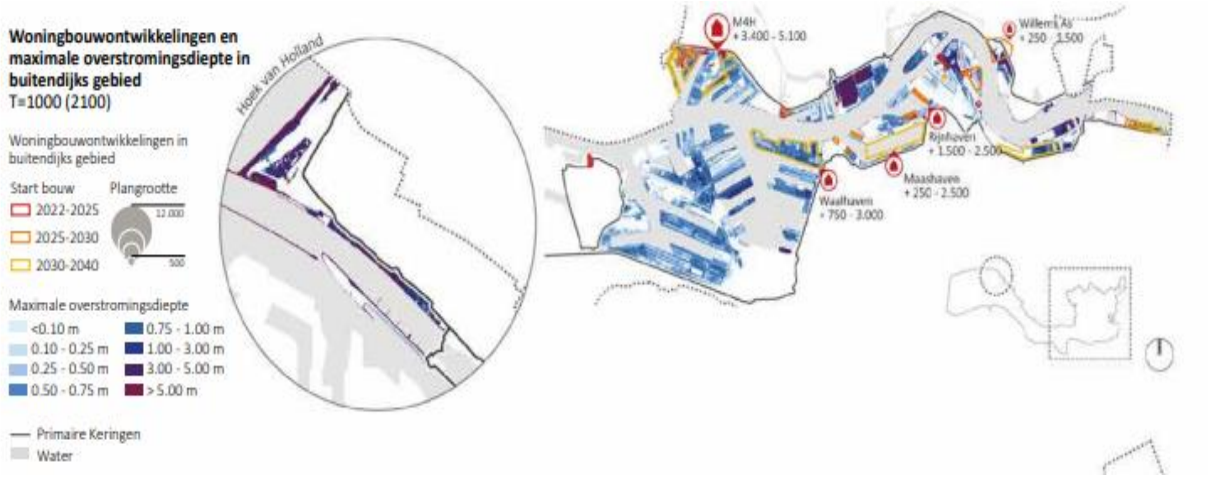


4.4.4 Purpose validity

The purpose of the CCS is one of the main themes that have been brought up during the interviews. This category of purpose validity refers to whether the purpose of the CCS is suitable for the phase in the policy cycle. To put it differently, it is concerned with the relevance of SLR information within the CCS. For the water board HD and RWS WNZ, the necessary data are delivered by the KNMI, meaning that there is no usability gap in this segment found for these stakeholders.

Considering the municipality or the port, it is noticebale that information based on nationally obtained data (such as KNMI scenarios, klimaateffectatlas) does not always match the information needs of these stakeholders. According to the municipality of Rotterdam**,** the goal of CCS based on nationally obtained data (such as KNMI or Klimaateffectatlas) is to get a rough idea about the impacts of SLR. For this purpose, these CCS can be seen as useful according to the municipality. However, when the municipality wants to give advice to a project developer, more specific or detailed information is needed. ‘’A chart with a pixel level of 100 by 100 meters could be too low, meaning that we have different goals when using the CCS. If you really want to give advice to project developers, you need to have data with a high level of resolution’’ (Municipality of Rotterdam, 2022). Therefore, the municipality makes rather use of its own CCS such as the Klimaatopgaven in Kaart, which provides charts with a higher pixel level.

Figure 15: Example of detailed information in Klimaatopgaven in Kaart



The Port of Rotterdam mentioned the same issue. The lack of detailled information within CCS based on nationally obtained data (such as the Klimaateffectatlas) has been the reason for the port to make their own CCS. The port want to have a detailed and accurate understanding of SLR impacts (e.g. flood risks) in the port region, while the goal of CCS based on national data is to get a rough idea on SLR impacts. By using self-made CCS, it can be assured that SLR information is accurate and up-to-date which is needed to make well informed decisions. Besides that, the port states that the KNMI scenarios are not relevant when you want to communicate strategies to the users of the port. ‘’This type of information is relevant for scientists, who want to know when the Maeslantkering will be insufficient with regards to SLR (Port of Rotterdam, 2022). Eventually, usability gaps were found in this segment for the municipality and the port.

4.4.5 Purpose readability

Purpose readability refers to whether the purpse of the CCS is clear to the end-users of the CCS. Stakeholders responsible for SLR adaptation may act before understanding the problem. All respondents were aware about the purposes of the used CCS. Also, various CCS have been created in order to meet the goals of the stakeholders with different responsibilites. Therefore, no usability gap was found in this area.

4.4.6 Purpose interactivity

Purpose interactivity refers to whether users can change or modify the purpose of the given CCS. For the used CCS, it was not possible to change its purpose. However, it was not mentioned to be an issue within all interviews, as various CCS exist with different kinds of purposes. RWS WNZ did argue that it could be useful to repurpose certain information in order to visualize data differently when giving a presentation to policy makers. In that way, other stakeholders could interpret complex information better. However, there are many CCS available to fulfill this need, which mean that there is no usability gap in this segment.

4.4.7 Information validity

Within this category, it will be discussed whether the shown SLR information in the CCS is correct or trustworthy. The CCS should provide an accurate reflection of the situation the stakeholder is using the CCS for. Within the interviews, every respondent has answered that the uncertainty that is coming with SLR is difficult to manage. SLR information, especially the information from the KNMI scenarios, cover a time scale of 50 years, 100 years or even further. This is one of the reasons why awareness about the issue of SLR is relatively low among the general public, as it seems to be too far in the future. Also, all respondents argue that the KNMI scenarios encompas a broad bandwidth containing less extreme to very extreme scenarios and people do not seem to agree on which scenario is most likely to happen.

In practice, this is strongly linked with development projects (e.g. housing or energy transition) with a lifespan of at least 50 – 100 years. Project developers need be sure that their project is resilient towards SLR impacts, but it is difficult to estimate when over- or underinvestment will happen which also lead to economic uncertainties (municipality of Rotterdam, 2022). An aspect related to this, mentioned in all interviews, refers to the function of the Maeslantkering. It is difficult to predict at what period of time in the future this storm surge barrier will be insufficient with regards to flood risk protection and the accessibility of the Port, considering rising sea levels. Due to this uncertainty, it can be problematic when choosing the most sustainable strategy in terms of water safety and socio-economic benefits/losses.

Another aspect that has been pointed out by the municipality and the port, is that various CCS contain different sources regarding SLR impacts or adaptation strategies. ''This is a problem we experience in practice, as you can get two completely different interpretations regarding the same issue. Imagine a project developer that is going to build something at the Noordereiland. He might want to know whether it will stay dry in this area considering extreme climate scenario. It could be that the Klimaateffectatlas indicates that this area will stay dry, while a municipal map could suggest that this area will not stay dry'' (Municipality of Rotterdam, 2022). According to the municipality and the Port of Rotterdam, this is inconvenient and undesirable when it comes to creating adaptation strategies, because information in CCS is seen as less credible and legitimate in the eyes of many end users. Both the municipality and the port state that when it comes to SLR communication and adaptation, it is important to have accurate information that is used by everyone. The Port of Rotterdam argues that this has been a reason for making their own charts, as local data is more accurate and trustworthy. Besides that, it provides 'control' over what is being communicated for SLR adaptation (Port of Rotterdam, 2022).

Besides that, many CCS based on national data mainly focus on inner dike areas. According to the Port of Rotterdam, outer dike areas such as the Port need a different approach is needed in terms of modeling water safety. The port of Rotterdam did this by using its own CCS, so that each part of the harbor could create its own strategy. This can also be linked to the level of pixels given in CCS. The lack of detailled information within CCS such as the Klimaateffectatlas has been the reason that the Port of Rotterdam decided to create its own CCS. By doing so, the port made sure that more accurate information has been made available to make well informed decisions. Eventually, usability gaps have been found for all respondents.

4.4.8 Information Readability

Information readability means whether it is clear what SLR information is shown in the CCS. For all respondent, it is clear what type of information is given to them. These respondents knew which CCS to use for the different responsibilities and information is structured among a variety of CCS. The municipality of Rotterdam does mention that it could be useful to add a feature that provides an explanation of the interpretation of data. ''When someone has developed a method to visualize a climate impact, certain data is used for that. If you actually want to make choices for certain policies with that method, it is useful to understand how the data is interpreted and what information is used for this'' (Municipality of Rotterdam, 2022). This means that a usability gap can be found for the municipality of Rotterdam.

4.4.9 Information interactivity

Information interactivity is about whether the stakeholders can change or modify the given information. There are interactive functions within CCS such as Klimaateffectatlas, Kaarten Waterveiligheid or Maatregelen Waterveiligheid as it is possible to click on different features that provide different information. However, none of the interviewers stated that information can be modified within the used CCS, but it was not mentioned to be a problem either.

However, RWS WNZ and the Port of Rotterdam both argued that a tool in which rising sea levels in combination of the sustainability of the current adaptation strategy are visualized could be something very beautiful. In this case, an interactive map could be created in which the most recent research will be updated, so that you can see what the consequences will be of SLR on, for instance, the flood defense system, how much it will cost and when it is needed to go for an alternative strategy. RWS WNZ compared this to a CS called 'Blokkendoos', in which people could visualize certain adaptive measures in relation to Room for the River projects (part of previous Delta Program). In this CS, it was possible to click on certain adaptation strategies and based on that people could see how much the water levels of rivers would drop. Creating such an interactive map is, however, very difficult and expensive to realize according to the Port of Rotterdam. It is therefore not seen to be a usability gap, but just an idea for future CCS.

4.4.10 Visual format validity

The visual format validity is about whether the visual mode is suitable for showing an accurate representation of SLR. Although it is uncertain what exactly will happen considering SLR, the water board HD and RWS WNZ argue that the visual format of scenarios serves as a base for their information needs. SLR is an uncertain theme and by using scenarios, multiple options for adaptation solutions can be addressed.

To create awareness however, it is more useful to use charts or storylines or -maps in which in a simple way is explained what the consequences of SLR will be. The municipality and the port have multiple CCS available, with different visual modes. (Interactive) maps of flood risks are most suitable for showing the local impacts of SLR. This is provided in many CCS used by the municipality and the port, such as Klimaateffectatlas, Rotterdams Weerwoord, Klimaatopgaven in Kaart or Kaarten Waterveiligheid. Also, story maps and charts are useful to communicate complex information in order to raise awareness or to visualize simple adaptation solutions. These are available for all respondents, meaning that there is no usability gap found.

4.4.11 Visual format readability

This category refers to whether the visual mode, and its way of reading, is clear. To put it differently, it should be understandable for the responsible stakeholders how the visual format of the CCS should be read. Especially for creating awareness or to simplify complex information, the visual mode is important to make stakeholders able to understand what is being said in the CCS. The water board HD and RWS WNZ argue that they have the expertise to understand the way the scenarios should be read.

The municipality and the port mentioned that interpreting raw data from the KNMI scenarios can be difficult. For the understanding and the communication of SLR information, it is important to provide information in storylines, charts or interactive maps. Scenarios containing a time scale of 50 – 100 years are not useful for creating local adaptation strategies. Therefore, a usability gap arises in the use of KNMI scenarios when used by the Municipality or Port.

4.4.12 Visual format interactivity

The last category refers to which CCS can be changed or modified in terms of zoom, level, color scheme or other visual options. The water board HD and RWS WNZ both replied that it is not possible to change information from the KNMI and Delta scenarios, but it is also not seen as something that would increase the usability of the CCS. ''Is it really necessary to provide such features when you talk about such uncertainties in a long future? I think that you have to make some robust decisions, so I am kind of wondering what you would need. I tend to say it is not needed when it comes to water safety (Water board HD, 2022). Furthermore, there were no usability gaps found in the interviews.

4.4.13 Overview of factors influencing usability gaps within CCS used in Rotterdam

In table 13, 14 and 15, an overview is given of factors explaining the usability gaps by making use of the framework proposed by Raaphorst et al (2020). The usability gaps differ among the respondents, which has mainly to do with the information needs and the responsibilities of the respondents.

Table 13*: Factors explaining usability gaps in case study Rotterdam*

	Validity	Readability	Interactivity
Stakeholder		**Municipality of Rotterdam** - Municipalities, project developers and inhabitants do not have expertise to work with KNMI scenarios. More simplified information is needed that can be used immediately **Port of Rotterdam** - KNMI scenarios not usable for creating local adaptation strategies. SLR communication should be visualized in simple way, so that port users understand what feasible adaptation solutions could be.	
Purpose	**Municipality of Rotterdam** - Regarding advice to project developers, high resolution level is needed in CCS about SLR impacts (detailed/accurate information). Goal CCS based on nationally obtained data (such as Klimaateffectatlas or KNMI scenarios) is to get a rough idea of SLR impacts, which does not meet the goal of the municipality. **Port of Rotterdam** - SLR impacts need to be shown with high resolution level for port area. Goal CCS based on nationally obtained data is, however, to get a rough idea about SLR impacts, which does not meet the goal of the municipality		
Information	**Water board Hollandse Delta** - KNMI scenarios contain very broad bandwidth. Much uncertainty which scenario is likely to happen. Lead also to economic uncertainties regarding planning of adaptation strategies. **Rijkswaterstaat West-Nederland Zuid** - KNMI scenarios contain very broad bandwidth. Much uncertainty which scenario is likely to happen. Lead also to economic uncertainties regarding planning of adaptation strategies	**Municipality of Rotterdam** - It is useful for policy making to add features that provide explanation of the interpretation of data in CCS.	

	<u>Municipality of Rotterdam</u> - Uncertainty on which scenario is likely to happen. Lead to economic uncertainties regarding planning of adaptation strategies - SLR information in CCS often based on different sources, leading to different results or interpretations regarding the same issue **<u>Port of Rotterdam</u>** - Much uncertainty which scenario is likely to happen as bandwidth KNMI scenarios are broad. Lead to economic uncertainties regarding planning of adaptation strategies - SLR information in CCS often based on different sources, leading to different results or interpretations regarding the same issue. Therefore, preferable to use self-created CCS for SLR adaptation as it provides control over what is being communicated towards port users. - Most CCS based on nationally obtained data are not suitable for outer dike areas.		
Visual format		**<u>Municipality of Rotterdam</u>** - format of KNMI scenarios are difficult to read. For understanding and communication SLR information, charts and storylines are easier to read. **<u>Port of Rotterdam</u>** - Format of KNMI scenarios are difficult to read. For understanding and communication SLR information, charts and storylines are easier to read	

Color coding for table 13	
	Not applicable for the respondents
	Applicable for 1 respondent
	Applicable for 2 respondents
	Applicable for 3 respondents
	Applicable for 4 respondents

Table 14: Overview factors explaining the usability gaps during understanding phase in case study Rotterdam

SLR Information needs during the understanding phase mentioned by the respondents	Recalled by	Information needs that were not met by CCS	Usability gap category	Factor(s) influencing usability gap
In-depth Information on local SLR impacts	Municipality of Rotterdam	CCS based on nationally obtained data (e.g. Klimaateffectatlas or LIWO) do not provide in-depth information for local areas.	Effectiveness	Purpose validity
		Various CCS provide differences in SLR information and results	User satisfaction	Information validity

				Information readability
	Port of Rotterdam	CCS based on national data (e.g. Klimaateffectatlas) do not provide in-depth information for port area	Effectiveness	Purpose validity
		Various CCS provide differences in SLR information and results	User satisfaction	Information validity
Visualizing of SLR / ease of use	Municipality of Rotterdam	KNMI scenarios are too complex for communicating SLR information	User satisfaction	Stakeholder readability Visual format readability
	Port of Rotterdam	KNMI scenarios are too complex for communicating SLR information	User satisfaction	Stakeholder readability Visual format readability

Table 15*: overview of factors influencing the usability gaps during the planning phase in case study Rotterdam*

SLR Information needs during planning phase mentioned by the respondents	Recalled by	Information needs that were not met by CCS	Usability gap category	Factor(s) influencing usability gap
Guidance in assessing/planning strategies	Water board HD	KNMI scenarios provide insights in future SLR, but there are still uncertainties. This leads to issues when planning adaptation measures or other socio-economic developments	User satisfaction	Information validity
	RWS WNZ	Not everyone agrees on which scenario should be followed when adapting to SLR. Lead to uncertainties in socio-economic developments in relation to SLR	User satisfaction	Information validity
	Municipality of Rotterdam	It is difficult to estimate when over- or under-investments will be made considering SLR scenarios	User satisfaction	Information validity
	Port of Rotterdam	Costs and benefit analysis can be done by using the CCS. However, calculating the risk reduction of local adaptation strategies can be difficult as a lot of data is needed.	User satisfaction	Information validity

4.5 Case study Vlissingen

SLR is projected to become an increasingly pressing issue in the coming years for the coastal city of Vlissingen (Samenwerking Klimaatadaptatie Zeeland, 2021; Programma Zuidwestelijke Delta, n.d.). Vlissingen, which has about 45.000 inhabitants, is a historic coastal city located in the southwestern Netherlands in the province of Zeeland. Just like Rotterdam, Vlissingen is located in a low-lying area, with almost every part being below sea level. Due to its location next to the North Sea, Vlissingen has been able to acquire rich maritime history, with a harbor that still is an important center of trade and commerce (Gemeente Vlissingen, n.d.). The latter belongs to the third seaport area and the second pilotage region of the Netherlands. In Vlissingen, you will also find famous builders of naval ships and mega yachts, maritime heritage and other companies, institutions and activities that have created the maritime character (Gemeente Vlissingen, n.d.). Nowadays, Vlissingen is a popular tourist destination, known for its beaches and other cultural attractions such as the boulevard. Most parts of the city are protected by dikes, with some exceptions. According to all interviewees, the Boulevard of Vlissingen and the two ports of Vlissingen (Vlissingen-Oost & Buitenhaven, belonging to the North Sea Port) are located outside the dikes.

***Figure 16**: Chart of Vlissingen (Kaarten & Atlassen, n.d.)*

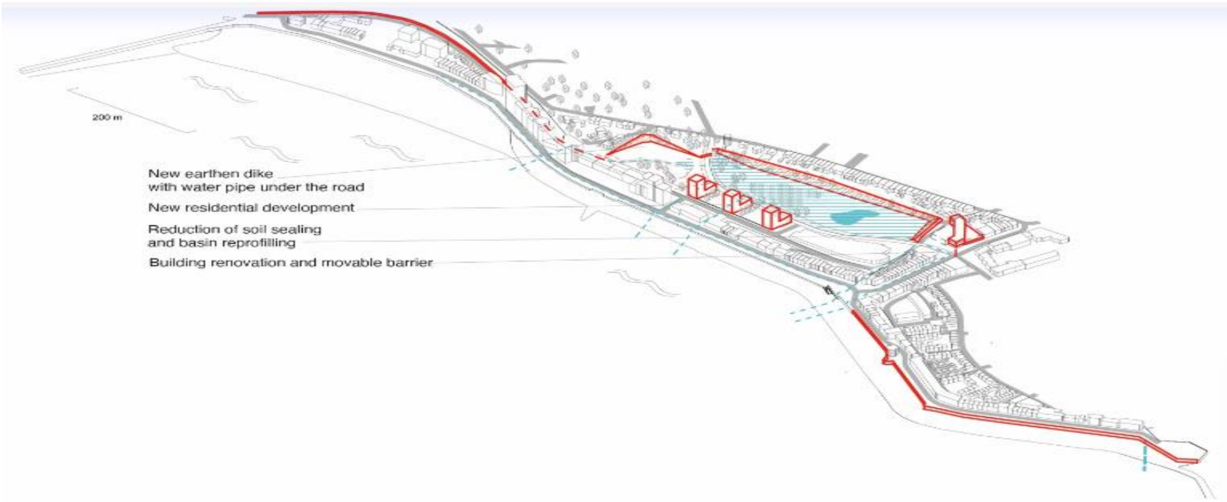
When it comes to Vlissingen, SLR is particularly referred to a higher chance of flooding (Samenwerking Klimaatadaptatie Zeeland, 2021; Programma Zuidwestelijke Delta, n.d.). This is no surprise, as the Province of Zeeland has been flooded heavily during the storm surge of 1953. Right now, strong protection measures have been implemented, such as the reinforcement of existing primary sea dikes, the implementation of innovative storm surge barriers and the creation of green spaces that can absorb excess water in the event of a flood (Programma Zuidwestelijke Delta, n.d.). However, according to all respondents, SLR will challenge this system in the future more often, which means that other adaptation strategies could be needed in the future as well. Besides that, the outer dike areas are considered to be most important according to the interviewees regarding SLR adaptation. For example, flooding could occur more often at the Boulevard of Vlissingen, which leads to socio-economic risks. In addition, all respondents have mentioned that SLR could affect the North Sea Port of Vlissingen in the future. The port is built at 4-5 meters above NAP in an outer dike area (Municipality of Vlissingen, 2023). Right now, there are no serious risks for this area, but it could become more vulnerable to flooding and salinization when sea levels will rise (Municipality of Vlissingen, 2023; Water board SDS, 2023). Considering the amount of investments that are being made in this area regarding e.g. the energy transition, it could be desirable to anticipate to future SLR in this area by creating feasible adaptation solutions (Municipality of Vlissingen, 2023).

***Figure 17**: Boulevard of Vlissingen (Boulevard 17, n.d.)*

Adaptation strategies towards SLR do already exist in Vlissingen. For instance, all respondents mentioned that Vlissingen is part of the SARCC project, in which is discussed how to integrate themes like water safety, use of space, natural quality and the economic potential of the coast. This has resulted in various adaptation strategies at the Boulevard of Vlissingen and in the creation of the vision regarding the 'Spuikom'. The latter is an inner dike water buffer meant to lead water from inundation or flooding towards it (Water board SDS, 2023). When creating this water buffer, SLR scenarios for the year of 2100 have been included (Iuorio & Bortolotti, 2023). This project is visualized in figure 15. However, considering SLR, other adaptive might be difficult to realize in Vlissingen, as there is limited space within the city according to all respondents. To strengthen the primary dikes, space is needed and that arises the question how the dikes should be enforced (inland or seaward dike reinforcement). Within Vlissingen, there are many monumental sights, making adapting to SLR more difficult to manage according to all respondents. On the other hand, dike reinforcement towards the sea can conflict with the conservation of the Natura 2000 area and the location of the fairway alongside the coast (Municipality of Vlissingen, 2023).

Besides that, beach erosion is considered to be problematic when sea levels rise. The beaches of Vlissingen are subjected to erosion and SLR will make this worse in the future. If these beaches disappear, it will have a negative impact on the tourism sector of Vlissingen. Therefore, it is important to have a sustainable strategy for this problem. Right now, RWS ZD mentioned that sand suppletion is used to assure that the beaches remain as it is now. The main reason for doing this, is that the beach and the dunes are important for the protection against flooding coming from the North Sea. However, it is possible that the sand suppletion strategy will become too costly in the future. Sand suppletion is not the only strategy that is used by RWS ZD. According to the RWS ZD, a dredging strategy within the Westerschelde is also needed, in order to keep it navigable for ships. Other than that, SLR is also associated with the supply of fresh water and to some extent salinization. According to the respondents, these issues are more related to the agriculture within Zeeland, which is not much present within the city of Vlissingen.

***Figure 18**: Making space for water: Spuikom (Iuorio & Bortolotti, 2021)*



4.6 CCS used during SLR adaptation process in Vlissingen

When it comes to the stakeholders involved in SLR adaptation in Vlissingen, multiple CCS have been mentioned. First of all, the water board SDS mentioned the KNMI scenarios and the IPCC report to calculate future water levels around Vlissingen. These CCS are also used for determining the possible effects of SLR. The results of these scenarios will be used in software tools to determine the future hydraulic boundaries and pressure for the primary dikes around Vlissingen. Also, information from the SLR knowledge Program is used for understanding SLR and creating adaptation solutions. Therefore, the KNMI scenarios and information from the SLR Knowledge Program serve as a way to understand SLR effects on areas like Vlissingen. Based on these results, a preferred strategy will be set up, which is provided in the Program Zuidwestelijke Delta (part of National Delta Program). However, it should be noted that the SLR Knowledge Program and the program Zuidwestelijke Delta are not CCS considering the definition of CCS used in this research.

RWS ZD also mentioned that the KNMI scenarios are important, as these provide insights in whether the preferred strategy is still sufficient. Scenarios are used to understand the extent to which sea levels will rise and when this will happen. This information is needed to see whether the current strategies regarding the primary flood defense system, fresh water supply and sediment management (sand suppletion and dredging) will be sufficient in the future. It should be noted that Rijkswaterstaat does not have a formal responsibility to the dike area in Vlissingen, as the water board is responsible for this dike area. RWS ZD does, however, have a role within the SLR Knowledge Program, in which it still affects Vlissingen. Also, RWS ZD recalled the SLR Knowledge Program as a source for finding information, but this is not a CCS. Besides that, the Zeespiegelmonitor (Sea Level Monitor, created by Deltares) is also mentioned for gathering information about the average sea levels. Based on the KNMI scenarios, information from the SLR Knowledge Program and de Zeespiegelmonitor, a preferred strategy within the Program Zuidwestelijke Delta is created.

The province of Zeeland replied that the KNMI scenarios are needed to understand what the SLR impacts will be in Zeeland (and also Vlissingen) Also, flood risk charts that are provided by the province themselves within the Themakaarten Klimaat are mentioned. In this interactive map, vulnerable areas can be identified regarding flood risks. Some charts of the water board SDS are also provided in the Themakaarten Klimaat.

The municipality of Vlissingen replied that the municipality of Vlissingen makes use of the KNMI scenarios to understand the effects of SLR for Vlissingen. Besides that, SLR information can be found in the adaptation strategies coming from the Klimaatadaptatiestrategie Zeeland (KasZ). In this Report, SLR effects for Vlissingen have been described and potential strategies have been addressed as well. The municipality of Vlissingen also cooperates with other institutions, such as the water board, Province, Zuidwestelijke Delta and RWS. The latter is not a CCS when considering the definition of CCS used in this research.

Table 16: *Overview of CCS used in Vlissingen for SLR adaptation*

CCS	Used by	Goal CCS	Information	Visual representation
KNMI scenarios (based on IPCC report)	Water board SDS RWS ZD Province of Zeeland Municipality of Vlissingen	Show national SLR impacts / creating awareness	Trend, expectation and various scenarios based on CO2 emissions ahead of 2050 - 2100	Scenario
Zeespiegelmonitor	RWS ZD	Showing status of average sea levels along the Dutch coast	Research results Deltares of sea levels along Dutch coast	Report
Themakaarten Klimaat	Province of Zeeland	Showing regional climate impacts	Impact of drought, heat, inundation and flooding	Interactive map
Klimaat adaptatiestrategie Zeeland (KasZ)	Municipality of Vlissingen	Communicating climate impacts and addressing action points for local decision-makers	Results of risk dialogue between governmental institutions in Zeeland, the Province and water board and action points to improve vulnerabilities in Zeeland.	Report

4.7 SLR information needs and the usability of CCS

Now the used CCS have been described, the information needs of each stakeholder will be shown for Vlissingen. After that, the information needs will be labelled into effectiveness, efficiency or user satisfaction. How these three are identified, is up to the respondents themselves. Eventually, it will be explained if these information needs are met, in order to identify potential usability gaps. Eventually an overview is given of the given answers and potential usability gaps

4.7.1 Water board Scheldestromen

Most answers related to the information needs stated by the water board SDS can be placed into the category of **effectiveness** (accuracy and completeness of goals). The water board SDS need to assure that, considering rising sea levels, Vlissingen will not suffer the consequences of flooding. The task of the water board SDS is therefore to prevent the city by maintaining the primary dikes. To be able to do so, datasets are needed on SLR the extent to which sea levels will rise and when this is going to happen. Based on that, it can be calculated whether the primary dikes comply with the provided hydraulic boundaries. It is possible that dikes need to be strengthened, which could have impact on the dike reservation zone and the use of space in Vlissingen. However, due to the fact that there are many monumental sights in Vlissingen, major adjustments are difficult to realize. This raises the question whether the dikes need to be strengthened seawards or landwards. Also, if big development projects are planned nearby or on the dikes, the water board needs information on future SLR, to see what adaptation strategies are needed with regards to flood safety and the socio-economic consequences.

Information needs are also found in the category of **user satisfaction** (accessibility, ease of use). SLR is a highly uncertain issue and, because of that, the water board SDS needs scenarios that provide guidance in planning adaptation strategies. This information is necessary, as decisions regarding the preferred strategy in the Zuidwestelijke Delta should be based on it.

4.7.2 Rijkswaterstaat Zee en Delta

Regarding RWS ZD, information needs were only found in the category **effectiveness.** Regarding the coastal city of Vlissingen, RWS ZD answered that datasets are needed about when and to what extent sea levels will rise in the future. This information is needed for the sand suppletion strategy at the coast of Vlissingen, which is essential for the protection of Vlissingen from flooding coming from the North Sea. Besides flooding, Rijkswaterstaat need to ensure that shipping routes to Vlissingen remain navigable. Right now, a dredging strategy is used and information is needed about the effect of SLR on this strategy as well. Lastly, information is needed about the impact of SLR on the fresh water supply.

Also, RWS ZD mentioned information needs in the category of **user satisfaction**. RWS ZD should know whether the preferred strategy is still sufficient or that an alternative strategy is needed, considering the amount of SLR and the socio-economic costs and bates of different strategies. Therefore, the scenarios should provide guidance or starting point in order to choose certain adaptation strategies.

4.7.3 Province of Zeeland

Regarding the province of Zeeland, information needs arise in the category of **effectiveness,** as the province should be able to find in-depth and recent data on SLR impacts in coastal areas of Zeeland (such as Vlissingen). Besides that, information about how to integrate SLR adaptation strategies with other spatial interests such as housing, nature or energy transition. The respondents of the province argue that the use of space is limited in Vlissingen, which means it is desirable that spatial interests such as housing, nature or energy transition will be built in the right place. However, there is a need for CCS that connect the effects of SLR with these other spatial interests.

Information needs are also found in the category of **user satisfaction**. For many policy makers, SLR is an issue that is way too far in the future, which prevents them for taking short- or long-term adaptation measures. The province argues that information should be made 'manageable' for decision-makers, or to put it differently, information that is easier to understand. ''Understanding SRL by a graph with a certain code is for policy makers or inhabitant useless'' (Province of Zeeland, 2022). Policy makers need starting points to improve their decisions on a short term. According to the province, this can only be achieved by increasing awareness or urgency and by lowering uncertainties about SLR.

4.7.4 Municipality of Vlissingen

The municipality of Vlissingen need different information than the other stakeholders. The answers of the municipality were mainly found in the category of **effectiveness**. First of all, it is needed to identify the local vulnerabilities for flood risks, especially in the outer dike areas such as the boulevard or business sides at the beach. CCS should provide in-depth information about SLR impacts in the specific living areas of Vlissingen.

The main issue for the municipality Vlissingen, however, is about remaining a 'livable' coastal city considering the consequences of SLR. What is meant by this is that Vlissingen should be protected from future flood risks, while staying an attractive tourist city as well. For instance, the recreative and economic function of the beach and the boulevard should be preserved in the future as well. The same applies for monumental sights within the inner dike areas as well, if sea levels rise for more than 2 meters. Therefore, the municipality of Vlissingen need information to integrate multiple spatial interests such as tourism, business opportunities, housing, nature or energy transition with SLR. Therefore, information is needed on the livability of Vlissingen in relation to SLR.

In relation to that, the municipality of Vlissingen argues that most tasks regarding SLR can be found at the water board or Rijkswaterstaat. Right now, the municipality of Vlissingen would like to be more involved in the integral assignment of reinforcement towards future flood risks. For example, when sea levels are rising, the focus will be on strengthening the dikes and the sand suppletion strategy. However, this could be very expensive and a large amount of space is needed for this. In order to find adaptation strategies that keep in mind the livability of Vlissingen as a coastal city, the municipality wants to cooperate more with stakeholders such as the water board SDS and RWS ZD. Regarding CCS, this would mean that e.g. information regarding dike reinforcements should be combined with nature-based solutions or opportunities for businesses. Therefore, CCS should provide information on the divisions of tasks regarding SLR, so that all spatial interests can be combined.

Besides that, information needs in the category **user satisfaction** can be found. The municipality mentions that it is needed to have accessibility to the available CCS that provide information for Vlissingen. It should therefore be noted that the municipality of Vlissingen is unaware about the existing CCS of which an overview is given in table 6 (chapter 3). Besides that, information should be created in a way that is suitable for decision-makers, which means that information must provide feasible adaptation solutions in a comprehendible text or visualization (ease of use).

4.7.5 Usability (gaps): are information needs met by the CCS?

In this segment, the usability of the CCS will be discussed, which means that the information needs will be compared with the provided information of the CCS. First of all, the water board SDS did not see many reasons why KNMI scenarios would be unusable for the water board Scheldestromen. ‘’I think that we can use the scenarios quite effectively’’ (Water board SDS, 2023). The water board SDS argues that people working at for this institute have the needed expertise to work with graphs and statistics, because SLR strategies are based on these factsheets. It is, however, mentioned that it can be difficult to determine which KNMI scenario is going to happen in the future which means that not all uncertainties can be diminished when planning adaptation strategies. Also, the chances of the least and most extreme scenarios are not given in the KNMI scenarios. Therefore, slight usability gap can be identified when using the KNMI scenarios.

RWS ZD also states that the CCS can be used effectively. Based on these graphs and statistics, Rijkswaterstaat is able to calculate whether certain strategies are still sufficient. ‘’People working for this institution do have the knowledge to prepare strategies for future situations’’ (RWS ZD, 2023). It is said by RWS ZD that the factor of uncertainty is impossible to diminish, but scenarios provide guiding points for managing these uncertainties. This means that the provided information is considered to be usable for RWS ZD.

The province of Zeeland, on the other hand, argue that the KNMI scenarios are not entirely suitable for policy making on a regional/local level. The KNMI scenarios do not provide accurate or local information, it does not integrate spatial interests with SLR adaptation, it does not provide guidance for making short- and long-term decisions and the visualized information is often difficult to understand. Furthermore, the flood risk map on the site of the province of Zeeland (Themakaarten

Klimaat) does not provide the possibility to understand flood risks in relation to SLR. Therefore, many usability gaps arise in the CCS used by the Province of Zeeland.

The municipality of Vlissingen need different information than is provided in the KNMI scenarios, as the scenarios are not suitable for planning and managing adaptation strategies on a local level. The used CCS do not provide information on SLR impacts on a local level and do not include the integration of spatial interests (e.g. housing, nature or energy transition) with the SLR adaptation process. In addition, information on integrating different responsibilities regarding SLR adaptation is lacking (organizational information needs / governance). This information is needed, because the municipality wants to integrate the process of dike reinforcement with the spatial interests of the municipality. Besides that, the municipality does gain more insights by using the Klimaatadaptatiestrategie Zeeland (KasZ). However, also in this CCS usability gaps were identified, as this report is not entirely specified for the city of Vlissingen. Another point mentioned by the municipality of Vlissingen is that there is little knowledge about the available CCS and it is needed to have access to other CCS that can be used for creating local adaptation strategies. Lastly, information should be communicated in a simple way, so that it is attuned to local policy makers and inhabitants.

In table 17 and 18, the information needs and whether these needs are met by the CCS are shown. In the last row, the green color means that there is no usability gap, the yellow color indicates a slight usability gap and the red color implies that there is a clear usability gap.

***Table 17**: Usability (gaps) CCS used in Vlissingen during the understanding phase*

SLR Information needs during the understanding phase mentioned by the respondents	Recalled by	Are information needs met by used CCS? Yes / Somewhat / No)	Usability (gap) category
Accessibility to CCS	Municipality of Vlissingen	There is little knowledge about existing CCS that provide information for local SLR adaptation	User satisfaction
Information on when and to what extent sea levels will rise (incl. return period).	Water board SDS	KNMI scenarios provide data sets on when and to what extent SLR could rise	Effectiveness
		KNMI scenarios do not contain the probabilities of which scenarios will occur	User satisfaction
	RWZ ZD	KNMI scenarios provide data sets on when and to what extent SLR could rise. Also, Zeespiegelmonitor helps when measuring average sea levels along the Dutch coast.	Effectiveness
Datasets/robust Information on SLR impacts	Water board SDS	KNMI and Delta scenarios provide data sets/robust information that can be plotted in software tools. Eventually, the SLR impacts can be calculated on current preferred strategy (in relation to hydraulic boundaries of flood defense system)	Effectiveness
	RWS ZD	KNMI scenarios provide data sets/robust information that can be plotted in software tools. Eventually, the SLR impacts can be calculated on current preferred strategy (in relation to sand suppletion strategy)	Effectiveness
In-depth information on local SLR impacts	Province of Zeeland	KNMI scenarios do not provide in-depth information on regional SLR impacts.	Effectiveness
		Flood risk maps of the Themakaarten Klimaat do not contain (an interactive function for) SLR information	Effectiveness
	Municipality of Vlissingen	KasZ provides information on local SLR impacts	Effectiveness
		KNMI scenarios do not provide information on local SLR impacts (flooding)	Effectiveness
Visualization of SLR impacts / ease of use	Province of Zeeland	KNMI scenarios are too complex for policy makers or inhabitants to understand regional/local SLR risks or to raise awareness	User satisfaction

	Municipality of Vlissingen	KasZ does summarize local SLR risks in a comprehendible way, containing a report and charts	User satisfaction
		KNMI scenarios are too complex for creating awareness or for creating adaptation strategies	User satisfaction

***Table 18**: Usability (gaps) CCS used in Vlissingen during the planning phase*

SLR Information needs during the planning phase mentioned by the respondents	Recalled by	Are information needs met by used CCS? (Yes / Somewhat / No)	Usability (gap) category
Guidance in assessing / selection adaptation strategies	Water board SDS	KNMI scenarios provide data that can be used to comprehend which strategy is most sufficient. However, technical and socio-economic uncertainties will remain	User satisfaction
	RWS ZD	KNMI scenarios provide data that can be used to comprehend which strategy is most sufficient.	User satisfaction
	Province of Zeeland	KNMI scenarios and Themakaarten Klimaat do not provide guidance in creating short- and long-term adaptation strategies	User satisfaction
Information on integrating SLR adaptation with spatial interests (nature, housing, energy, tourism etc.)	Province of Zeeland	KNMI scenarios and Themakaarten Klimaat do not provide information on integrating multiple spatial interest with SLR adaptation	Effectiveness
	Municipality of Vlissingen	KNMI scenarios do not provide information for the integral assignment of the dike reinforcement in Vlissingen. Division of tasks should be integrated for creating a 'livable' coastal city	Effectiveness
		KasZ provide to a certain extent an integration of spatial interests with SLR adaptation. However, less information is found on the integral assignment of the dike reinforcement in Vlissingen.	Effectiveness
Visualization of possible adaptation strategies / ease of use	Province of Zeeland	KNMI scenarios do not provide visualizations of adaptations strategies. Need for a format that provide information that is directly applicable for policy makers	User satisfaction
	Municipality of Vlissingen	KasZ provide textual format and charts that are understandable for policy makers and inhabitants	User satisfaction
		KNMI scenarios do not provide visualizations of adaptations strategies. Need for a format that provide information that is directly applicable for policy makers	User satisfaction

4.8 Factors influencing usability gaps

In this segment, the factors that influence the usability gaps will be described. For every stakeholder, the identified factors will be place into the 12 potential factors proposed by Raaphorst et al (2020).

4.8.1 Stakeholder validity

The first category is about whether the desired action is the responsibility of the targeted audience. It is important that the CCS reaches and affects the right/responsible audience. According to the water board SDS and RWS ZD, information from the CCS they make use of (e.g. KNMI scenarios or Zeespiegelmonitor) is attuned to their responsibility.

The province and the municipality**,** on the other hand, argue that the KNMI scenarios do not provide information that meet their SLR responsibility. Both governmental sides argue that information coming from the KNMI scenarios mainly focus on the extent to which sea levels will rise. This information important for understanding if the current primary dikes will be sufficient in the future, but that is not the task of the province or municipality. The responsibility of the province or the municipality is to create a sustainable living environment and information is needed to integrate themes like nature, housing, agriculture or energy transition with the adaptation of SLR. The municipality stated that information on adaptation strategies were mostly found in the KasZ.

In addition, the municipality of Vlissingen mentioned that it would be useful to provide information on the division of tasks. Right now, the municipality of Vlissingen wants to be involved more in integral assignment of the dike reinforcement. This is needed in order to remain to ensure the future livability of the coastal city. For instance, it could be that the water board needs to strengthen the dikes, but by doing so, it will have a negative impact on the visual attractiveness of the city. When the municipality would be involved in this process a more desirable option could emerge, as, for example, dikes will be strengthened while adding nature-based solutions. However, the municipality argues that most tasks regarding SLR (like flood defense, fresh water supply) can be found at the water board and RWS, meaning that the municipality has limited influence in the SLR adaptation process. Eventually, usability gaps can be found for the Province of Zeeland and the Municipality of Vlissingen.

4.8.2 Stakeholder readability

Stakeholder readability refers to whether the visual language, and its possible connotations, of the CCS match the interpretive frames of the audience. To put it differently, SLR information within a CCS should be understandable for the targeted audience. When talking to the water board SDS and RWS ZD, it became clear that there was no trouble when understanding information from the used CCS. ‘’We have many technicians and ‘nerds’ working at our water board. Especially for technical solutions, we basically need to know how the information is composed and which sources have been used’’ (Water board SDS, 2023). RWS ZD had a similar reply, stating that employees of RWS ZD are used to work with scenarios from the KNMI.

However, for creating awareness among the general population, other CCS are needed according to the water board and RWS ZD. An example is provided by RWS ZD which mentioned overstroomik.nl, in which SLR is visualized in a more simple way. Because of the fact that these two stakeholders were aware of available different CCS for raising awareness among the general population, no usability gap is found for the water board SDS and RWS ZD. On the contrary, the province and municipality argued that there is a need for new CCS to raise awareness, as the feeling of urgency regarding SLR is low among the inhabitants of Zeeland. The province of Zeeland even provided the suggestion to make these new CCS accesible for elementary schools, so that the future generation can become acquainted with the theme of SLR.

Besides that, the province of Zeeland mentioned that the graphs and tables coming from the KNMI scenarios are difficult to understand for policy makers. The province especially refers to the time scales that are being used in the KNMI scenarios. ‘’For many people, time scales of 50 or 100 years are way too far in the future. Although policy makers want to adapt to SLR, but they do not know *what* to do against it. A time scale for hundred years does not say much to a policy maker. A decision-maker looks at these graphs and will think that a rise of sea level with 1,20m would be much. However, a decision-maker could also argue that sea levels will rise with only 20 centimeters, so what would they be worried about?’’ (Province of Zeeland, 2022). What would be more usable, is to make use of a specified amount of rise in sea levels (e.g. 10-millimeter SLR for the year of 2050). This is more understandable than the graphs and tables used by the KNMI. The province argues that a similar concept is used for the Belgian coast. The Flemish coastal vision basically assumes that sea levels will inevitably rise by 3 meters and, because of that, each generation needs to adapt for 1 meter of SLR.

When it comes to the municipality of Vlissingen, it became clear that the KNMI scenarios are difficult to understand due to the extent of uncertainty that is coming along with it. However, the municipality of Vlissingen argued that by collaborating with parties such as the water board, RWS or the province, it became clear what might happen regarding SLR. Besides that, this information is also mentioned within the KasZ, which is used for climate adaptation. ''In that sense, we make more indirectly use of the KNMI scenarios'' (Municipality of Vlissingen, 2023). Eventually, usability gaps arise in this category for the province of Zeeland and the municipality of Vlissingen.

4.8.3 Stakeholder interactivity

Within this category, it will be discussed whether the visual literacy required for interpreting the CCS is suitable for the targeted audience (stakeholder interactivity). It is about the link between the complexity of data and its relation to the visual literacy of the involved stakeholder. Some CCS may have interactive functions, but these need to be attuned to the interpretive frames of the audience. The water board SDS and RWS ZD argue that for technical solutions, it is not per se needed to interact with information. It could be better to just show the data sets. Therefore, no usability gap exists in this segment for these stakeholders.

On the contrary, the province responded that for local decision making or creating awareness a certain degree of interactivity could be useful. By doing so, policy makers of inhabitants can by interacting become more aware of the theme of SLR. This is also linked to the stakeholder readability. Therefore, a usability gap can be found at the CCS used by the province of Zeeland.

4.8.4 Purpose validity

Purpose validity refers to whether the purpose of the CCS is suitable for the phase in the policy cycle (understanding, planning, managing). To put it differently, the goal of the CCS needs to be relevant for the problem the stakeholders are using the CCS for. Regarding the water board SDS and RWS ZD, the goal is to find information on future SLR and its impacts, which can be done by the KNMI scenarios and the Zeespiegelmonitor. Therefore, water board SDS and RWS ZD did not mention any usability gap in this category.

The province of Zeeland did mention usability gaps in this segment. The goal of KNMI scenarios is to inform about a possible rise in sea levels and its consequences, while the goal of the province is to find detailed information on SLR impacts and to make well informed decisions on a regional/local level, both on the short- and long term. Besides that, the flood risk map of Themakaarten Klimaat does not include SLR information, as it only portrays the current flood risks.

The municipality of Vlissingen also stated that the goal of the KNMI scenarios is completely different compared to the goal that the municipality wants to use a CCS for. First of all, the KNMI scenarios do not provide information on local SLR information. Besides that, the KNMI scenarios do not provide relevant information on creating policies on a local level. ''A lot of research has been done, but we mostly use them to understand the vulnerabilities in specific areas in Vlissingen. The results of the KNMI are interesting, but for making decisions it is not relevant'' (Municipality of Vlissingen, 2023). The question is rather how to integrate multiple aspects like housing, nature, tourism and flood protection into a sustainable vision. More relevant information can be found in the KasZ, in which adaptation strategies are found. However, the KasZ does not specifically mention information regarding the integral assignment of the dike reinforcement. Eventually, a usability gap can be found for the municipality considering the use of the KNMI scenarios and the KasZ.

4.8.5 Purpose readability

Purpose readability refers to whether the purpose of the CCS is clear to the stakeholders. When talking to the respondents, none of them mentioned anything about not understanding the purpose of the used CCS. Therefore, no usability gap has been found in this segment.

4.8.6 Purpose interactivity

Purpose interactivity refers to whether users can change or modify the purpose of the given CCS. For all respondents, it is not possible to change the purpose of the CCS. For the water board SDS, RWS ZD and the municipality of Vlissingen this was not a problem. Only the province stated that it could be useful to change the purpose of the Thema Kaarten Klimaat, as it does not provide SLR information in this interactive map. Therefore, a usability gap was found for the province of Zeeland.

4.8.7 Information validity

Information validity refers to whether the given information is an accurate reflection of the situation the stakeholder is using the CCS for. Most of the respondents stated usability gaps in this segment, especially regarding the KNMI scenarios. The water board, the province and the municipality stated that the bandwidth of the KNMI scenarios is very broad. Also the most and least extreme scenario regarding SLR are not most likely to happen. ''For instance, the chance exists that Antarctica will melt completely which would result in an extreme rise in sea levels. However, it is not mentioned that the probability of this is less than 1%. But the assumption is apparently that you still need to keep this scenario in mind'' (Water board SDS, 2023).

Besides that, the water board HD argues that many components contribute to the extent to which sea levels are rising. However, the KNMI scenarios do not take all aspects into account. This could lead to problems at different scales. For instance, KNMI scenarios calculate the extent to which sea levels will rise and what impact it will have on Dutch coastal areas in general. However, it is not translated for more specific areas such as the Westerschelde or Oosterschelde. Another point addressed by the water board SDS and the province of Zeeland, is that KNMI scenarios are always updated within a couple of years. This leads to differences in results every time new scenarios are created. The water board SDS mentioned that it is more useful to pick a certain rise in sea levels (e.g. 1 meter) and to make use of the scenarios to determine in which year this amount of SLR will occur.

In addition, the municipality of Vlissingen, talked about needing access to other CCS regarding this issue. Right now, the awareness about the existing CCS is low, because there are multiple existing CCS available (as stated in table 6). Nevertheless, not having access to other CCS lowers the credibility of SLR information, due to the fact that less information can be found. Eventually, usability gaps were found in this segment for the water board SDS, province of Zeeland and the municipality of Vlissingen.

4.8.8 Information readability

Information readability means whether it is clear what SLR information is presented in the CCS. For the water board SDS and RWS ZD, it is clear what type of information is provided in the CCS. This means that there is no usability gap found within the CCS used by these stakeholders.

For the Province of Zeeland, it was not always clear what type of information was provided to them, considering the KNMI scenarios. ''You have to do first research yourselves to understand what these scenarios actually mean, but only a combination of numbers and letters are given. You really have to look very specifically, but it remains hard to understand what scenario will unfold in the future considering the amount of CO2 emissions'' (Province of Zeeland, 2022). Besides that, the scenarios do not give any information according to the province, as nobody can foresee the future and there are many factors other than the CO^2 emission like the melting of ice that influence SLR. ''I would think that it is useful to add those factors into the scenario as well, but these are considered to be external factors. Right now, I do not even know what this information is about'' (Province of Zeeland, 2022). This imposes a usability gap in this segment for the province of Zeeland.

4.8.9 Information interactivity

Information interactivity is about whether the stakeholders can change or modify the given information. For the CCS used by the respondents, this is not possible. Only in the KNMI scenarios and in the Themakaarten Klimaat are some interactive functions present, but these cannot be changed or modified. For the water board SDS and RWS ZD, it was not mentioned to be problematic.

According to the province of Zeeland, information about the costs and benefits of various adaptation strategies should be visualized in an interactive way, because that is something that would say something to a policy maker. ''If you show to policy makers what various coastal adaptation measures will costs and what it possibly could yield, I think that would be a very powerful technique''.

For the municipality of Vlissingen, information interactivity can be useful for integrating different roles and responsibilites of all responsible actors (water board, province, Rijkswaterstaat). The tasks of dike reinforcements should be visiualized and be merged with the spatial interests of the municipality. By doing so, all responsibilities of SLR adaptation are combined which can be usable for creating a sustainable and livable coastal city. Eventually, a usability gap could be found for the province and the municipality.

4.8.10 Visual format validity

The visual format validity is about whether the visual mode is suitable for showing an accurate representation of SLR. All respondents argued that scenarios in itself are useful for predicting multiple outcomes regarding future SLR. Although SLR is highly uncertain, scenarios can give insights in what could happen. Eventually, a preferred strategy can be made for the Zuidwestelijke Delta. A side note needs to be made as the water board SDS argued that not all scenarios within the bandwidth of the scenarios are likely to happen (as mentioned in section 4.8.7). According to the water board SDS, it could be useful to add percentages or a histogram about the likelihood of the given scenarios. For example, for an extreme scenario will be given a smaller percentage than an average scenario. By doing so, SLR scenarios can be showed in a more accurate way. Therefore, a slight usability gap can be found for the water board SDS.

For creating awareness, on the other hand, it would be more suitable to provide charts, maps or storylines in which e.g. the costs and benefits of multiple adaptation strategies are shown. Right now, these kinds of visual formats are lacking according to the province of Zeeland and the municipality of Vlissingen. Besides that, the municipality, argues that it is needed to provide digital or online CCS. However, there are multiple CCS available online, as stated in table 6. Eventually, a usability gap exists in the for the municipality of Vlissingen and the province of Zeeland.

4.8.11 Visual format readability

This category refers to whether the type of visual mode of the CCS, and its way of reading it, is clear to the users. To put it differently, is about the extent to which it is understandable how the visual format should be read. For the water board ZD and RWS ZD, there was no usability gap to be mentioned in this category, as there is enough knowledge and expertise to interpret the given reports, scenarios, graphs or tables of the KNMI. For creating awareness, other CCS like overstroomik.nl are used, as this CCS provide an interactive template which showing local flood risks in an easy way (RWS ZD, 2023). This is needed, because both the water board SDS and RWS ZD argue that the visual format of the KNMI scenarios is difficult to read by the general population.

Although the format of a scenario is usable for understanding a possible rise of sea levels, the information should be visualized differently to be usable for regional policy making, according to the province of Zeeland. Instead of using a graph of a rising sea level, the visual format should contain information on a specified amount of SLR for a certain year (e.g. 1 meter for 2050), referring to the Belgian coastal vision as mentioned earlier. By doing so, SLR adaptation is visualized differently which is more understandable for decision-makers. Eventually, a gap could be found for the province of Zeeland

4.8.12 Visual format interactivity

The last category refers to which CCS can be changed or modified in terms of zoom, level, color scheme or other visual options. The water board SDS and RWS ZD replied that this is not possible for the CCS they make use of. However, both stated that it is not a necessity to make well informed decisions, as people working for these institutions often have the needed expertise to work with data sets or 'raw data'. RWS ZD does, however, mention that an interactive chart is useful for visualizing SLR impacts or adaptation solutions such as strengthening dikes for a certain amount of SLR. ''I like GIS based applications in which you can click on certain relevant features. So that you can see how much a dike should be raised or where salinization will take place in a certain area'' (RWS ZD, 2023). However, this should not be seen as a usability gap, as it is just an idea for an easier way to visualize SLR impacts or adaptation. For the other respondents, there were also no clear usability gaps found for this segment.

4.8.13 Overview of factors influencing usability gaps

In table 19, 20 and 21, an overview is given of the factors that influence the usability gaps, based on the framework proposed by Raaphorst et al (2020). The usability gaps differ among the respondents, which has mainly to do with the information needs and the responsibilities of the respondents. It should be noted that the identified usability gaps are not in all CCS present as present as other usability gaps.

Table 19: *Factors explaining usability gaps in case study Vlissingen*

	Validity	Readability	Interactivity
Stakeholder	**Province of Zeeland** - KNMI scenarios not usable for responsibility of spatial adaptation. Information is needed about integrating multiple spatial themes (e.g. housing, nature or energy transition) **Municipality of Vlissingen** - KNMI scenarios not usable for responsibility of spatial adaptation. Information is needed about integrating multiple spatial themes (e.g. housing, nature or energy transition) in order to remain a 'livable coastal city - Information needed on integral assignment of dike reinforcement, which means that an integration of the different tasks of water board, RWS, province and municipality is needed for creating a 'livable' coastal city.	**Province of Zeeland** - New CCS are needed for raising awareness among general population. - Time scale difficult to understand in KNMI scenarios. Not suitable for spatial adaptation. Preferable to give specified amount of rise in sea levels, instead of possible scenarios. **Municipality of Vlissingen** - New CCS are needed for raising awareness among general population - KNMI scenarios difficult to understand and are therefore not usable for creating local adaptation strategies.	**Province of Zeeland** - Interactive carts of maps can help to raise awareness

Purpose	**Province of Zeeland** - Goal of KNMI scenarios is to give insights in when and to what extent sea levels will rise. However, the purpose of the province is to find accurate SLR information and to make well-informed decisions on a regional level. - Themakaarten Klimaat does not provide a function for SLR. Goal of Themakaarten Klimaat is to show current flood risks without mentioning SLR. **Municipality of Vlissingen** - Goal of KNMI scenarios is to give insights in when and to what extent sea levels will rise. However, the purpose of the municipality is to make well-informed decisions on a local level.		**Province of Zeeland** - Themakaarten Klimaat are interactive in which flood risks are provided. However, no information on SLR is included in it. Needed to change purpose.
Information	**Water board Scheldestromen** - KNMI scenarios contain broad bandwidth. Much uncertainty which scenario is likely to happen. - KNMI scenarios are not translated to more specific areas such as Westerschelde, because some datasets are missing. - KNMI scenarios are updated every couple of years. Lead to different results regarding the same issue. **Province of Zeeland** - KNMI scenarios contain broad bandwidth. Much uncertainty which scenario is likely to happen. - Not all datasets are taken into account in the KNMI scenarios. - KNMI scenarios are updated every couple of years. Lead to different results **Municipality of Vlissingen** - Municipality need access to other CCS that provide information about local adaptation strategies	**Province of Zeeland** - Unclear what kind of information is shown in scenarios. Only a combination of letters and numbers are given. - Not all factors influencing SLR are taken into account in scenarios, meaning that the scenarios do not say much about the future.	**Province of Zeeland** - Integrating information on costs and benefits of adaptation strategies within interactive map could be useful **Municipality of Vlissingen** - Useful to change information for integrating divisions of tasks for integral assignment dike reinforcement
Visual format	**Water board SDS** -There is a need to add percentages of the chance certain scenarios will happen. Right now, the least and most extreme scenarios need to be taken into account while the chance is very low that these scenarios will happen **Province of Zeeland** - For creating awareness and showing costs and benefits of adaptation strategies: maps, charts or storylines are needed **Municipality of Vlissingen** - For creating awareness and showing	**Province of Zeeland** - Format of KNMI scenarios are difficult to read. For understanding and communication SLR information, visualizing a specified rise in sea levels would be more understandable for policy makers	

	costs and benefits adaptation strategies, maps, charts or storylines are needed - Providing digital CCS would be useful for adapting to SLR (these do already exist)		

Color coding for table 19	
	Not applicable for the respondents
	Applicable for 1 respondent
	Applicable for 2 respondents
	Applicable for 3 respondents
	Applicable for 4 respondents

***Table 20**: Overview of factors influencing the usability gaps during the understanding phase in case study Vlissingen*

SLR Information needs during the understanding phase mentioned by the respondents	Recalled by	Information needs not met by used CCS	Usability (gap) category	Factor(s) influencing the usability gap
Accessibility of CCS	Municipality of Vlissingen	There is little knowledge about existing CCS that provide SLR information on a local level	User satisfaction	Information validity
Information on when and to what extent sea levels will rise (incl. return period)	Water board SDS	KNMI scenarios do not contain the probabilities of which scenarios will occur	User satisfaction	Information validity Visual format validity
In-depth information on local SLR effects	Province of Zeeland	KNMI scenarios do not provide in-depth information on regional SLR impacts	Effectiveness	Purpose validity
		Flood risk maps of the Themakaarten Klimaat do not contain (an interactive function for) SLR information	Effectiveness	Purpose validity
	Municipality of Vlissingen	KNMI scenarios do not provide information on local SLR impacts (flooding)	Effectiveness	Purpose validity
Visualization of SLR impacts / ease of use	Province of Zeeland	KNMI scenarios are too complex for policy makers or inhabitants to understand local risks or to raise awareness	User satisfaction	Stakeholder readability Stakeholder interactivity Information readability Visual format validity Visual format readability
	Municipality of Vlissingen	KNMI scenarios are too complex for policy makers or inhabitants to understand local risks or to raise awareness	User satisfaction	Stakeholder readability Visual format validity

Table 18*: Overview of factors influencing the usability gaps during the planning phase in case study Vlissingen*

SLR Information needs during the planning phase mentioned by the respondents	Recalled by	Information needs not met by used CCS	Usability (gap) category	Factor(s) influencing the usability gap
Guidance in assessing / selecting adaptation strategies	Water board SDS	KNMI scenarios provide data that can be used to comprehend which strategy is most sufficient. However, technical and socio-economic uncertainties will remain	User satisfaction	Information validity
	Province of Zeeland	KNMI scenarios and Themakaarten Klimaat do not provide guidance in creating short- and long-term adaptation strategies	User satisfaction	Purpose validity Information interactivity
Information on integrating SLR adaptation with spatial interest (nature, housing, energy, tourism etc.)	Province of Zeeland	KNMI scenarios and Themakaarten Klimaat do not provide information on integrating multiple spatial interest with SLR adaptation	Effectiveness	Stakeholder validity Purpose validity
	Municipality of Vlissingen	KNMI scenarios do not provide information for the integral assignment of the dike reinforcement in Vlissingen. Division of tasks should be integrated for creating a 'livable' coastal city	Effectiveness	Stakeholder validity Purpose validity Information interactivity
		KasZ provide to a certain extent an integration of spatial interests with SLR adaptation. However, less information is found on the integral assignment of the dike reinforcement in Vlissingen.	User satisfaction	Stakeholder readability Purpose validity Information interactivity
Visualization of possible adaptation strategies / ease of use	Province of Zeeland	KNMI scenarios do not provide visualizations of adaptations strategies. Need for a format that provide information that is directly applicable for policy makers	User satisfaction	Stakeholder validity Purpose validity
	Municipality of Vlissingen	KNMI scenarios do not provide visualizations of adaptations strategies. Need for a format that provide information that is directly applicable for policy makers	User satisfaction	Stakeholder validity Purpose validity

5. Conclusion

In this chapter, the sub-questions and the main question will be answered. During this research, qualitative research has been conducted with the following main question:

''Which factors explain the usability gaps in coastal climate services regarding sea level rise information in Dutch coastal cities when used during adaptation processes?''

multiple sub-questions have been created to answer the main question.

1. *What are the impacts of SLR for Dutch coastal cities?*
2. *Which of the available CCS regarding SLR information are used by the involved stakeholders?*
3. *What (type of) SLR information is shown in the CCS used by the responsible decision-makers?*
4. *What (type of) information about SLR impacts and/or adaption do the involved decision-makers need?*
5. *Which usability gaps can be identified within the used CCS?*
6. *Which factors can be identified that influence the usability gaps in CCS regarding SLR information?*

5.1 Conclusion on sub-questions

1. What are the impacts of SLR for Dutch coastal cities?

When investigating the cases of Rotterdam and Vlissingen, it became clear that there are similarities and differences regarding future SLR impacts. Within the context of Dutch water- and SLR management, it was no surprise that SLR is mostly associated with a higher chance of flooding. Dutch coastal cities experienced many flood events in the past (such as the storm surge of 1953), which eventually resulted in the creation of a strong flood defense system. However, the primary dikes and storm surge barriers should also protect Dutch coastal cities from flooding in the future, considering a rise in sea levels. With regards to Rotterdam, for example, a rise in sea level could mean that the Maeslantkering should be replaced for a sea lock. In Vlissingen, it could be that dike reinforcements are needed to adapt to SLR, which should be done landwards or seawards. However, in both cases it was mentioned that special attention should be given to outer dike areas, as these areas are more vulnerable for flooding (e.g. Noordereiland, the Boulevard or the port regions). Besides that, the port accessibility was explicitly mentioned in Rotterdam, as it is linked to the function of the Maeslantkering. In Vlissingen, on the other hand, SLR could affect the navigability of the fairways along the coast. However, beach erosion was considered to be more problematic in Vlissingen and attention should therefore be paid to the sand suppletion strategy in the future. Furthermore, other impacts were recalled as well in both cases (such as salinization or fresh water supply) but to a lesser extent.

2. Which of the available CCS regarding SLR information are used by the involved stakeholders?

As the result of the desk research, a variety of CCS were identified that van be used during both national and local decision-making processes. The most prominent CCS for SLR adaptation in the Netherlands are the KNMI climate scenarios, which are a national translation of the global IPCC report.

In these scenarios, information can be found on when and to what extent sea levels will rise in the future, which can be used for calculating the impacts on Dutch coastal cities. To find information that can be used for regional or local SLR adaptation, the Kennisportaal Klimaatadaptatie provide many interactive services such as the Klimaateffectatlas, NAS Adaptation Tool or the Climate Resilient Cities Toolbox.

During the interviews, it became clear that the KNMI scenarios are considered to be the main source for SLR information. For instance, the water boards and the regional departments of RWS in both cases argued that the KNMI scenarios are needed to understand when and the extent SLR will rise and what impacts it will have on a specific area. Eventually, this information is translated into the regional Delta Programs, which provide insights for planning and managing SLR adaptation. Besides the KNMI scenarios, the RWS ZD also mentioned the Zeespiegelmonitor for analyzing the mean sea level rise along the Dutch coast.

Considering the stakeholders responsible for spatial adaptation, it was stated that the KNMI scenarios are considered to be the most important source for SLR information as well. However, for translating SLR information to local adaptation strategies, other CCS are needed. This is where interesting differences in results were found between the case studies. It became clear that local stakeholders in Rotterdam (municipality, port) were more aware of the existing CCS than the respondents (province, municipality) in Vlissingen. Not all of the existing CCS were used in Rotterdam, but CCS like the Klimaateffectatlas and LIWO were mentioned by these stakeholders. Also, in order to gain more detailed insights in the vulnerabilities of flood risks, the municipality of Rotterdam and the Port created their own CCS, such as the Rotterdams Weerwoord, Klimaatopgaven in Kaart, Kaarten Waterveiligheid or Maatregelen Waterveiligheid. In comparison, the respondents of the local/regional governmental in Vlissingen (province, municipality) have little or no knowledge about the CCS that already exist. Most SLR information is therefore obtained from the KNMI scenarios. The municipality did mention that the Klimaatadaptatiestrategie Zeeland to be valuable for finding local adaptation strategies. Also, the Province of Zeeland mentioned a flood risk map that can be find on the web portal Themakaarten Klimaat, but this map does not include SLR information.

3. What (type of) SLR information is shown in the CCS used by the responsible stakeholders?

The respondents from the case studies recalled different kinds of CCS, which provided different types or visualizations of SLR information. Considering the water boards and the regional departments of RWS, the used CCS provide information on when and the extent to which sea levels will rise. For example, information in the KNMI scenarios is translated into multiple datasets, graphs or tables. Also, the Zeespiegelmonitor was mentioned by RWS ZD, which provide information in a report/textual format on the average rise in sea level along the Dutch coast. Most of these CCS provide data sets (or robust information) which eventually can be used in software tools to calculate what the impact of SLR will be on the flood defense system, fresh water supply, beach erosion or salinization. As a result, the used CCS mostly provide information regarding the understanding phase of SLR adaptation.

The municipality of Rotterdam and the Port of Rotterdam use different CCS. The KNMI scenarios and the Klimaateffectatlas are used to get a rough idea of SLR risks, while the CCS like the Rotterdams Weerwoord, Klimaatopgaven in Kaart or Kaarten Waterveiligheid are used to get more detailed information on a specific area in Rotterdam. In-depth information is mostly found in reports, charts or (interactive) maps, which is needed during the understanding and planning phase. Regarding the case of Vlissingen, the province of Zeeland and the municipality of Vlissingen argued that the KNMI scenarios are used during the understanding phase to understand SLR impacts. The province did recall that flood risk maps exist in the interactive map of Themakaarten Klimaat, but this CCS does not provide SLR information. The municipality, on the other hand, recalled the KasZ, which is a report in which possible adaptation strategies are mentioned.

4. What (type of) information about SLR impacts and/or adaption do the involved stakeholders need?

Various SLR information needs have been found within the interviews. Within the understanding phase, the categories of ‘accessibility of CCS’, ‘information on when and to what extent sea levels will rise’, ‘raw data/robust information on SLR impacts’, ‘in-depth information on local SLR impacts’ and ‘visualization of SLR impacts / ease of use’ have been found. During the planning phase, the categories of ‘guidance in assessing / planning adaptation strategies, ‘information on integrating spatial interests with SLR adaptation and ‘visualization of SLR adaptation strategies / ease of use’ have been identified. Information needs during the managing phase have not been recalled. The current preferred strategy is still considered to be sufficient in both cases, which could mean that no big adjustments are needed at this moment.

It became clear that SLR information needs vary a lot among the respondents, which is mainly due to the different SLR responsibilities of the stakeholders during the adaptation. For instance, the information needs of the water boards and the regional departments of RWS within both cases were very similar. Also, the recalled information needs mostly arise during the understanding phase and refer to the effectiveness of information. The main question for these stakeholders is to what extent SLR will rise and during what period of time. Based on that, the impacts on e.g. the current primary flood defense system or sand suppletion strategy could be calculated by plotting data coming from the KNMI scenarios in specific software tools. Besides that, these stakeholders need information that provide guidance regarding possible future adaptation solutions. The extent to which sea levels are going to rise is highly uncertain, but it is important to plan strategies in advance to get insights in which strategy will be most sustainable. This information need arises during the planning and can be placed into the usability category of ‘user satisfaction’, as reliable SLR information is needed that provide a grip on possible future adaptation strategies.

The municipality of Rotterdam and the Port of Rotterdam mentioned that in-depth or detailed information is needed on the vulnerable areas regarding flood risks, especially in the outer dike area. Also, the cost and benefits of possible adaptation strategies was seen as an aspect on which information should be provided. These needs arise in the understanding and planning phase, which can be placed in the usability category of effectiveness of information. In addition, SLR information should be visualized in a simple way for communicating purposes. For example, it is difficult for a project developer to understand what strategies should be made towards SLR when only complex KNMI scenarios are provided. Therefore, both the impacts and feasible adaptation strategies should be made visible in an easy way, which can be done by (interactive) maps, charts or schematic overviews of feasible adaptation strategies. Eventually, Information needs of the municipality of Rotterdam and the Port of Rotterdam arise in the understanding and planning phase, which can be placed in the usability category of user satisfaction.

The province of Zeeland and the Municipality of Vlissingen, on the other hand, mentioned information needs regarding SLR adaptation strategies in combination with other spatial interest (such as housing, tourism, nature or the energy transition). In addition, the municipality of Vlissingen has a demand for information on the division of tasks regarding the integral assignment of the dike reinforcements around Vlissingen. These information needs occur during the planning phase and can be placed into the category of effectiveness. Besides that, guidance is needed for creating short- and long-term strategies according to the province of Zeeland. These information needs arise in during the planning phase and within the user satisfaction category. Lastly, new CCS are needed that provide ‘simplified’

SLR information to policy makers or inhabitants in order to raise awareness and to create local adaptation strategies.

5. Which usability gaps can be identified within the used CCS?

Considering the different tasks regarding SLR of the respondents, it can be noted that there are differences in the extent to which usability gaps are being mentioned. For instance, only slight usability gaps were found within the CCS used by the water boards of both cases and the RWS WNZ, which was often related to the same issue. Although the KNMI scenarios provide data sets that can be used for calculating the impact of SLR on the current preferred strategy, it was argued that not every scenario within the bandwidth used in this CCS is likely to happen. Also, it was mentioned that the KNMI scenarios do not entirely provide guidance, as uncertainty with regards to SLR cannot be diminished completely. Because of that, it can be a bit more difficult to determine which scenario should be followed, while these organization need to base their future policies on. It remains therefore a bit more difficult to see what strategy would be most sustainable with regards to the future. In that sense, a slight usability gap arise in the category of user satisfaction within the KNMI scenarios used by the water boards and the RWS WNZ. This is, however, seen as a small issue and the KNMI scenarios can still be used effectively.

On the other hand, clear usability gaps have been recalled in CCS used by the stakeholders responsible for spatial adaptation (province, municipality or the port). Regarding the case of Rotterdam, multiple usability gaps were identified within CCS that are based on nationally obtained data. These include e.g. the KNMI scenarios and the Klimaateffectatlas, as these CCS are not usable in terms of effectiveness and user satisfaction. These CCS do not provide detailed/accurate information and do not visualize local adaptation strategies. Besides that, the information in the KNMI scenarios is seen as too complex. For communicating purposes, SLR information should be visualized in an easy way, so that it is directly applicable. Lastly, CCS do often provide different results regarding the same issue, which is undesirable when communicating SLR information. Because of all these reasons, it is preferable to make use of the self-created CCS (Rotterdams Weerwoord, Klimaatopgaven in Kaart, Kaarten Waterveiligheid or Maatregelen Waterveiligheid). In addition, it can be difficult to estimate the costs and benefits of certain adaptation solutions, due to the uncertainty that is coming along with the theme of SLR.

The municipality of Vlissingen and the province of Zeeland stated the most usability gaps. A side note should be made here, as these stakeholders were not entirely aware of the availability of existing CCS that can be used for SLR adaptation. Nevertheless, the main problem is that CCS such as the KNMI scenarios cannot be used effectively. For instance, KNMI scenarios do not provide any information that can be used for local decision-making, as only shows a possible rise in sea level with a time scale far into the future (e.g. 50-100 years) which does not say much to a policy maker. In addition to that, the province and municipality argue that little information is found on integrating SLR adaptation strategies with other spatial interests. It was argued that new CCS are needed that combine the tasks of different responsible stakeholders with regards to the integral assignment of the dike reinforcements around Vlissingen. What is coming along with that, is that CCS such as the KNMI scenarios do not provide information for short- and long-term solutions in relation to its costs and benefits. In that sense, many of the CCS used by the municipality or province cannot be used effectively during the planning and managing phase. In addition, usability gaps arise in the category user satisfaction, as information from KNMI scenarios are highly uncertain and often too complex to understand for policy makers. This usability gap arises during the understanding phase.

6. Which factors can be identified that influence the usability gaps of CCS regarding SLR information?

For both cases, a variety of factors have been identified that explain the usability gaps in the used CCS. In addition, all possible communicative qualities (validity, readability and interactivity) have been recalled during the interviews to some extent. However, it stands out that information validity was the most mentioned factor that influenced the usability gaps within the used CCS. This may not come as a surprise, because SLR is linked to time scales far into the future and it is hard to provide information that is correct or trustworthy. It also affects the way e.g. scenarios provide guidance during the planning phase. Besides that, purpose validity and stakeholder readability were recalled often within the cases. This had mostly to do with the fact that the KNMI scenarios or other CCS based on nationally obtained data are not suitable for stakeholders responsible for spatial adaptation, or that information is too complex to understand for policy makers, project developers or inhabitants.

The extent to which certain factors were address differed a lot among the stakeholders, which was (again) mainly due to the differences in SLR responsibilities. When it comes to the water boards and the regional departments of RWS, information validity explained mostly the existence of the slight usability gap within the use of the KNMI scenarios. For instance, it was answered that the bandwidth of the KNMI particular scenario are very broad, which does not entirely provide credible information on which strategy will be most sustainable from a socio-economic point of view. In relation, it was stated that not all data sets are included in the scenarios, which could lead to differences in mean SLR and SLR along specific areas of the Dutch coast (e.g. the Westerschelde). Besides that, it was mentioned the most extreme scenarios should be taken into account according to the KNMI scenarios, even though these scenarios are very unlikely to happen. The water board SDS mentioned that it would be useful to add percentages or a histogram next to the scenarios, referring to the visual format validity of the KNMI scenarios.

Considering the stakeholders responsible for spatial planning in both cases, a variety of factors were identified within both cases. Within Rotterdam, the municipality and the port mentioned that the factors of stakeholder validity, stakeholder readability, stakeholder interactivity, purpose validity, information validity and visual format readability influence the usability gaps. The municipality also considers that information readability is a factor that influences the usability gaps within the CCS based on national data. These factors were mostly about the detailed information within the CCS, the credibility of SLR information in various CCS and the way SLR information is attuned to policy makers or inhabitants.

The most factors were mentioned by the province of Zeeland and the municipality of Vlissingen. Factors that have been recalled by these stakeholders are stakeholder validity, stakeholder readability, stakeholder interactivity, purpose validity, information validity, information readability, information interactivity, visual format validity and visual format readability. These factors mostly referred to the fact that SLR information is highly uncertain and complex to understand for policy makers. Also, SLR information coming from the KNMI scenarios do not say much to policy makers regarding the planning of local adaptation strategies. SLR information was often seen as irrelevant for policy makers because it did not provide knowledge about integrating spatial interests with SLR adaptation. Lastly, it can be noted that the communicative quality of interactivity was mentioned the most by these stakeholders. This can mainly be explained by the fact that there is a lack of awareness about the existing CCS and that there is a need to involve the general population more within the process of SLR adaptation by using interactive visualizations.

5.2 Conclusion on the main question

During this research, an attempt has been made to answer the following main question:

''Which factors explain the usability gaps in coastal climate services regarding sea level rise information in Dutch coastal cities when used during adaptation processes?''

It can be concluded that the factors influencing the usability gaps within CCS used in Dutch coastal cities vary a lot among the responsible stakeholders. Almost every category within the template proposed by Raaphorst et al. (2020) has been recalled, with the exception of purpose readability and visual format interactivity. Usability gaps were identified during the understanding phase and the planning phase, depending on the responsibility of the stakeholder. Besides that, most usability gaps within these phases referred to a lack of effectiveness or a lack of user satisfaction. It became clear that the water boards and the regional departments of RWS only mentioned slight gaps within the category of user satisfaction, while the stakeholders responsible for spatial adaptation mentioned both usability gaps within the category of effectiveness and user satisfaction. It is also noticeable the efficiency of information (amount of resources spent in terms of time and money) have not been mentioned by any of the respondents. This can probably be explained by the fact that SLR information can be found quickly within CCS that are provided digitally. Also, most CCS are free to use by everyone.

The factor that was mentioned most by all respondents was information validity. SLR is highly uncertain and it is difficult to accurately predict what is going to happen. The way sea levels will rise and how fast this will go, depend on many factors, which are not all included in the KNMI scenarios. However, adaptation strategies should be planned in advance, as there are many interests within the use of space. The most important question that arises from this is how to integrate SLR adaptation with these spatial interests. However, SLR adaptation is costly in the short term and scenarios do not provide enough guidance to diminish these uncertainties, even if costs on the long term can be declined. Another what was mentioned a lot during the interviews, was the stakeholder readability. Most important information on SLR is mostly captured within the KNMI scenarios, which is difficult to translate to local decision making. Besides that, purpose validity was mentioned within both cases. For instance, the KNMI scenarios or other CCS based on nationally obtained data does not meet the goal of stakeholders responsible for spatial adaptation are using the CCS for.

However, the most noticeable differences in the factors explaining usability gaps were not found when comparing the results of case studies, but when comparing the responsibilities of the respondents. This is due to the fact that SLR is mostly associated with a higher chance of flooding. The main tasks for assuring flood protection, can be found at the water board and RWS. For over a century, these institutions have the primary task to defend Dutch cities against the consequences of flooding. It is no surprise that a lot of knowledge and experience for SLR adaptation can be found at these institutions. This was also stated by the respondents working for the water boards and RWS and it was also the main reason why static datasets provided within the KNMI scenarios can be used effectively. However, governments such as municipalities or provinces do not need to comply to certain rules that are stated in the Water Act (with an exception for the outer dike areas). Although a sustainable use of space is needed with regards to SLR, the most task for SLR management can be found at institutions such as the water board and Rijkswaterstaat. This might also be the reason why CCS are mostly attuned to stakeholders such as the water boards or RWS. Despite that, it is possible that spatial planning will become more important in the future. Therefore, usability gaps within CCS recalled by the stakeholders responsible for spatial adaptation need to be solved, in order to avoid future maladaptation.

6. Discussion

In this chapter, a reflection will be presented about the obtained results from this research in relation to the used theoretical frameworks and existing literature. Also, the limitations of this research will be highlighted and recommendations for practical use and future research will be shown.

6.1 Reflection

First of all, it should be noted that two concepts within the conceptual model have not been brought up during the interviews. The first category entails the management phase. The reason that the management phase has not been identified can possibly be explained by the fact that new KNMI scenarios are going to be revealed in October 2023, while this research has been conducted before this date. It could be that, when interpreting the new KNMI scenarios, an alternative strategy has to be created. At this moment, the preferred strategies within Rotterdam and Vlissingen still comply to the rules of the Water Act, meaning that within both cases no big adjustments are needed (yet). Besides that, the category of (lack of) efficiency has not been mentioned during the interviews. An explanation for this could be that most CCS are available online and free to use.

Despite that, the template proposed by Raaphorst et al. (2020) has been useful for the identification of the experiences of various responsible stakeholders with regards to the factors that influence the usability gaps within CCS. This template also offers the opportunity to distinguish the categories of validity, readability and interactivity, meaning that a broad range of possible usability gaps is taken into account. In addition, this template could be integrated within the interview guide, in order to help the respondents identify usability gaps within different categories. Eventually, it was possible to categorize all results within this template and the obtained results can be used for the creation of new CCS that are usable for stakeholders with different kinds of responsibilities.

Besides that, it should be noted that many recalled usability gaps could be explained by multiple factors, as these were interrelated to each other. Considering the case of Vlissingen, for example, the province of Zeeland argued that stakeholder readability was mentioned to be a factor that influenced the usability gap when using the KNMI scenarios. This CCS was often too complex to understand for policy makers or to raise awareness among the general population. However, stakeholder interactivity was also mentioned by the province, which influenced the same usability gap. Another example can be found when analyzing the answers of the water board SDS. According to the water board SDS, the bandwidth of the KNMI scenarios is very broad, while not every scenario within this range is likely to happen (information validity). However, the water board SDS mentioned that it would be useful to add percentages or a histogram, so that the chances of the KNMI scenarios are visible (visual format validity). In that sense, two factors can influence the same usability gap.

In addition, some of the categories within the framework proposed by Raaphorst et al. (2020) were mentioned more often than other factors in this research. For instance, it became clear that the category of information validity was recalled the most. This could possibly be explained by the fact that SLR is associated with high level of uncertainty and complexity, which means that most attention is being paid to the (quality of the) data itself. Moreover, all respondents argued that it is impossible to diminish all uncertainties regarding when and the extent to which sea levels will rise. Nevertheless, the KNMI scenarios provide multiple possible scenarios to which adaptation strategies should be made. It remains, however, unclear how the future will unfold.

Besides that, the categories of purpose validity and stakeholder readability were mentioned many times, especially by stakeholders responsible for spatial adaptation. This might reflect the way Dutch coastal cities have dealt with water-related issues in the past and the different kinds of responsibilities towards SLR adaptation. For example, the water boards and RWS have always had a very prominent function when it comes to flood risk management for a very long period of time. It could be that the most important source for SLR information (KNMI scenarios) is therefore especially attuned to these kinds of stakeholders. Nevertheless, it is recognized during the last couple of decades that spatial adaptation towards SLR is getting more important and that stakeholders like provinces, municipalities or ports should be more involved during the adaptation process. However, the current CCS regarding SLR information may not always be attuned to these responsibilities and the level of expertise of these kinds of stakeholders. Also, stakeholders responsible for spatial adaptation often argued that not many CCS exists that raise awareness among the general population. This may also imply that these kinds of stakeholders are not involved (enough) during the creation of CCS.

In addition, not all respondents mentioned clear usability gaps. Especially the water boards and the regional departments of RWS only recalled slight usability gaps within the used CCS. In some cases, these were even mentioned as points of improvements, as it did not affect the decision-making process. Based on that, it can be argued that the CCS used by these stakeholders are already usable. It is very likely that this is due to the fact that a lot of expertise is available at the water boards and the regional departments of RWS regarding water or SLR management.

Another point that needs to be addressed, is that most usability gaps arose within the category of validity and readability, while the category of interactivity was mentioned the least. It could be that there is a lack of understanding or awareness about the benefits of the (visual) interactivity of CCS. Stakeholders may not consider interactive data to be necessary or may not know how interactive visualizations can help facilitate decision making. For example, the water boards and the regional departments of RWS did not mention data interactivity to be necessary as these institutes already have the needed knowledge and expertise to work with data from the KNMI scenarios. Regarding the stakeholders responsible for spatial adaptation, it was stated that simple type of CCS or visualizations of SLR information are needed to understand SLR risks and to create adaptations strategies. However, not all respondents were able to answer how interactive functions could play a role that would help during the adaptation process. This may be due to the fact that an interactive map does not per se provide reliable SLR information, as SLR projections can be very uncertain and a lot of local data is required to achieve some level of accuracy.

When comparing the results from this research to other existing literature, it can be noted that the results are quite similar. The demand for CCS is driven by decision-makers that have an interest in SLR adaptation or coastal risk prevention. However, due to a large thematic and geographical diversity, the SLR information needs differ among the regions of the world (Le Cozannet et al., 2017). This was to some extent observed in the two Dutch cases as well. Due to these variety of thematic and geographics within coastal cities, the creation of usable CCS can be problematic as it is hard to meet all the SLR information needs. Besides that, Vaughan et al. (2014) and Le Cozannet et al. (2017) mentioned some reasons that hinder the use of CCS, such as a limited awareness about the long-term effects of SLR, a lack of credible or legitimate SLR information, a lack of relevant SLR information or a lack of knowledge regarding long term costs and benefits. These usability gaps were also mentioned within this research to a high extent. On the contrary, Vollstedt et al. (2021), argued that co-production is needed between scientists and end-users of CCS to close usability gaps. This has not been mentioned during any interviews within this research.

6.2 Limitations

Although the choices regarding the used methods have been explained, it is important to highlight the limitations of this research. First of all, a qualitative analysis has been conducted in this research, which was useful for obtaining in-depth data. The desk research and the semi-structured interviews provided the opportunity to investigate the two selected cases thoroughly. Various factors that influence the usability gaps in the used CCS have been identified for different stakeholders. However, the results coming from the cases Rotterdam and Vlissingen have not been compared to other cases within different countries. For instance, the use of CCS depend on many factors, such as the geographical location, the socio-economic situation of countries, the way there has been dealt with water related issues in the past or SLR awareness. It is therefore possible that the results from this research could differ from coastal cities located in other (European) areas.

In addition, it should be noted that a mixed-method study would have been most suitable for conducting this research. Although this research has a high internal validity, the obtained results are difficult to generalize. A quantitative survey, for instance, could have increased the external validity by obtaining results from multiple cases across different countries in Europe. Especially when creating an open web portal that can be used for multiple European coastal cities (which is the goal of the CoCliCo project), it is needed to have data that can be generalized.

Another point that should be discussed is the fact that not all stakeholders use the same CCS. In addition, some of the mentioned CCS were only used by one respondent (e.g. Themakaarten Klimaat, Zeespiegelmonitor, KasZ or Maatregelen Waterveiligheid). The experienced usability gaps and the factors influencing them within (some of the) CCS could therefore be biased. A way to avoid this problem, is to make use of a particular CCS as a case study instead of using a coastal city as a case study. When investigating a particular CCS (such as the Klimaateffectatlas), insights for the same CCS can be obtained by multiple stakeholders that make use of it.

Lastly, the choice has been made to interview multiple institutions and governments with different responsibilities within a particular case study. However, it should be addressed that the answers provided by a given institution (e.g. provinces) may be completely different from those of the same institutions within other cases. A different method could be to select one particular institute or government that has a particular SLR responsibility (for example municipalities), in order to identify the usability gap on a certain management level. By doing so, more internal validity can be assured on what is needed by one type of stakeholder. Within this research, for instance, only one interview has been done with a province or port. In addition, the respondents of the water boards and RWS all had a technical function towards flood risk management. These respondents are likely to have lots of knowledge regarding SLR information from the KNMI scenarios. Therefore, it can be recommended to interview other people from these institutions that have a role towards policy making. This could lead to different results.

6.3 Recommendations

Based on the findings, some recommendations can be done for practical use and for further research. First of all, regarding practical use, it became clear that not all the respondents were aware of the available CCS that can be used for SLR adaptation. Many of these CCS are, for example, provided on web portals such as Kennisportaal Klimaatadaptatie. However, these kinds of platforms should be communicated more effectively towards stakeholders responsible for SLR adaptation and citizens. A simple way to do so could be to appoint a certain commission that speaks to decision makers about the possibilities of the existing CCS.

In addition, there is a need for new CCS that is designed to raise SLR awareness among general population. Attention should be paid especially to the ease of use of the CCS, because SLR information should be communicated in a comprehensible way. Within this research, it became clear that providing (interactive) visualizations within the CCS are crucial for achieving this goal. Therefore, it can be recommended to involve inhabitants within the creation of CCS. Related to this, it could be useful to provide CCS for educational purposes. When CCS are being used at elementary schools (e.g. during geography classes), future generations will be involved in the process of SLR adaptation. By doing so, awareness could increase regarding this issue.

Another point that can be addresses is about short- and long-term decision making regarding SLR adaptation. When and to what extent sea levels will rise is highly uncertainty, but in order to take adaptive measures the level of uncertainty needs to be decreased. It can therefore be recommended to introduce a framework that enables policy makers to reflect on their decisions. Instead of using a broad bandwidth of possible scenarios in the future, it could be beneficial to combine a certain amount of rise in sea levels with short- and long- term decisions. For instance, it could be that it is expected that in the year of 2080 sea levels will rise by 50 centimeters. When this is known, certain methods for flexible decision making can be introduced that guides policy makers during the adaptation process to this specific rise in sea levels. By doing so, policy makers (especially those responsible for spatial adaptation) could have a better understanding in what adaptive measures should be taken, considering a given period in time.

For further research, it can be recommended to conduct a survey across multiple countries in Europe. As mentioned previously, this research is part of the European CoCliCo project. Conducting a survey across multiple cases in Europe would increase the external validity of the results. By doing so, generalizable data can be obtained which can be useful for the creation of a European web-portal regarding SLR adaptation.

Another recommendation could be regarding the user involvement during the creation of CCS. Most CCS have been created by using a 'top-down' approach, meaning that scientific research is brought towards those in need of SLR information. However, when both scientist and stakeholders would work together when creating CCS, it is more likely that the usability of the CCS would increase. By doing so, scientists could directly apply the SLR information needs of multiple stakeholders within the CCS. At the same time, stakeholders responsible for SLR adaptation could discuss with scientists how a good CCS would look like. This could possibly bridge the gap between science and practice.

Lastly, further research could be done about the possibilities of an interactive map that shows several SLR risks and the short- and long-term costs and benefits of various adaptation strategies. This was mentioned by some participants of this research as something that would be beautiful to visualize. Besides that, decision-makers might be more willing to take action sooner, as the short- and long-term costs and benefits would be displayed. This may, however, be difficult to realize due to the fact that a lot of (local) data is needed on SLR risks and possible adaptation strategies in a specific area. Also, attention should be paid to the reliability of the data that is being displayed in this kind of CCS. For example, the costs and benefits might fluctuate strongly due to the uncertainty regarding SLR or the economic situation within a country.

7. References

Alexander, M., & Dessai, S. (2019). What can climate services learn from the broader services literature? *Climatic Change*, *157*(1), 133–149. https://doi.org/10.1007/s10584-019-02388-8

Alonso-Ríos, D., Vázquez-García, A., Mosqueira-Rey, E., & Moret-Bonillo, V. (2009). Usability: A Critical Analysis and a Taxonomy. *International Journal of Human-Computer Interaction*, *26*(1), 53–74. https://doi.org/10.1080/10447310903025552

Ayers, J., & Dodman, D. (2010). Climate change adaptation and development I. *Progress in Development Studies*, *10*(2), 161–168. https://doi.org/10.1177/146499340901000205

Barron, S., Canete, G., Carmichael, J., Flanders, D., Pond, E., Sheppard, S., & Tatebe, K. (2012). A Climate Change Adaptation Planning Process for Low-Lying, Communities Vulnerable to Sea Level Rise. *Sustainability*, *4*(9), 2176–2208. https://doi.org/10.3390/su4092176

Bevan, N., Carter, J., Earthy, J., Geis, T., & Harker, S. (2016). *New ISO Standards for Usability, Usability Reports and Usability Measures*. SpringerLink. Retrieved on 19th October 2022, from: https://link.springer.com/chapter/10.1007/9783319395104_25?error=cookies_not_supported&code=4f78d5b4-36d1-45e4-8092-a2fce27f650c

Brasseur, G. P., & Gallardo, L. (2016). Climate services: Lessons learned and future prospects. *Earth's Future*, *4*(3), 79–89. https://doi.org/10.1002/2015ef000338

Brömmelstroet, M. T. (2013). Performance of Planning Support Systems. *Computers, Environment and Urban Systems*, *41*, 299–308. https://doi.org/10.1016/j.compenvurbsys.2012.07.004

Bryman, A. (2008). Social Research Methods. New York: Oxford University Press.

Bryman, A. (2012). Social research methods (4th edition). Oxford, United Kingdom: University Press

Burrell, G., & Morgan, G. (2016). Sociological Paradigms and Organisational Analysis. Routledge.

Cash, D. W., & Belloy, P. G. (2020). Salience, Credibility and Legitimacy in a Rapidly Shifting World of Knowledge and Action. *Sustainability*, *12*(18), 7376. https://doi.org/10.3390/su12187376

Cazenave, A., & Cozannet, G. L. (2014). Sea level rise and its coastal impacts. *Earth's Future*, *2*(2), 15–34. https://doi.org/10.1002/2013ef000188

Cazenave, A., & Llovel, W. (2010, January 1). Contemporary Sea Level Rise. *Annual Review of Marine Science*, *2*(1), 145–173. https://doi.org/10.1146/annurev-marine-120308-081105

Cerreta, M., & Toro, P. D. (2010). Integrated spatial assessment for a creative decision-making process: a combined methodological approach to strategic environmental assessment. *International Journal of Sustainable Development*, *13*(1/2), 17. https://doi.org/10.1504/ijsd.2010.035096

Creswell, J. W. (2003). *Research design: Qualitative, quantitative, and mixed methods approaches (2nd ed.).* Thousand Oaks, CA: Sage.

Creswell, J. W., & Poth, C. N. (2017). *Qualitative Inquiry and Research Design (4th ed.)*. SAGE Publications.

Clark, P. U., Shakun, J. D., Marcott, S. A., Mix, A. C., Eby, M., Noland, R. B., Levermann, A., Milne, G. A., Pfister, P. L., Santer, B. D., Schrag, D. P., Solomon, S., Stocker, T. F., Strauss, B. H., Weaver, A.

J., Winkelmann, R., Archer, D. F., Bard, E., Goldner, A., . . . Plattner, G. (2016). Consequences of twenty-first-century policy for multi-millennial climate and sea-level change. *Nature Climate Change*, *6*(4), 360–369. https://doi.org/10.1038/nclimate2923

Cortekar, J., Bender, S., Brune, M., & Groth, M. (2016). Why climate change adaptation in cities needs customized and flexible climate services. *Climate Services*, *4*, 42–51. https://doi.org/10.1016/j.cliser.2016.11.002

Cortekar, J., Themessl, M., & Lamich, K. (2020). Systematic analysis of EU-based climate service providers. *Climate Services*, *17*, 100125. https://doi.org/10.1016/j.cliser.2019.100125

European Environment Agency (2021). *Global and European sea level rise*. Retrieved on 29th May 2022, from: https://www.eea.europa.eu/ims/global-and-european-sea-level-rise

Findlater, K., Webber, S., Kandlikar, M., & Donner, S. (2021). Climate services promise better decisions but mainly focus on better data. *Nature Climate Change*, *11*(9), 731–737. https://doi.org/10.1038/s41558-021-01125-3

Gemeente Rotterdam (2019). *Rotterdams Weerwoord*. Retrieved on 5th May 2022, from: Rotterdams Weerwoord

Gemeente Rotterdam (2022). Klimaatopgaven in Kaart. Retrieved on 21th July, from: https://rotterdamsweerwoord.nl/app/uploads/2022/03/DEF_klimaatopgaven-2030-in-kaart_toegankelijk_WT3.pdf

Goosen, H., De Groot-Reichwein, M. a. M., Masselink, L., Koekoek, A., Swart, R., Bessembinder, J., Witte, J. M., Stuyt, L., Blom-Zandstra, G., & Immerzeel, W. W. (2013). Climate Adaptation Services for the Netherlands: an operational approach to support spatial adaptation planning. *Regional Environmental Change*, *14*(1), 1035-1048. https://doi.org/10.1007/s10113-013-0513-8

Grier, R. A., Bangor, A., Kortum, P., & Peres, S. C. (2013). The System Usability Scale. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *57*(1), 187–191. https://doi.org/10.1177/1541931213571042

Guba, E. G., & Lincoln, Y. S. (1994). Competing paradigms in qualitative research. Handbook of qualitative research, 2(105), 163-194.

Haasnoot, M., Kwakkel, J. H., Walker, W. A., & Ter Maat, J. (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change-Human and Policy Dimensions*, *23*(2), 485–498. https://doi.org/10.1016/j.gloenvcha.2012.12.006

Hansen, A., & Bi, P. (2017, December). Climate change adaptation: no one size fits all. *The Lancet Planetary Health*, *1*(9), e353–e354. https://doi.org/10.1016/s2542-5196(17)30160-2

Hine, D. W., Reser, J. P., Morrison, M., Phillips, W. J., Nunn, P., & Cooksey, R. (2014). Audience segmentation and climate change communication: conceptual and methodological considerations. *WIREs Climate Change*, *5*(4), 441–459. https://doi.org/10.1002/wcc.279

Hinkel, J., Aerts, J. C. J. H., Brown, S., Jiménez, J. A., Lincke, D., Nicholls, R. J., Scussolini, P., Sanchez-Arcilla, A., Vafeidis, A., & Addo, K. A. (2018). The ability of societies to adapt to twenty-first-century sea-level rise. *Nature Climate Change*, *8*(7), 570–578. https://doi.org/10.1038/s41558-018-0176-z

Hinkel, J., Church, J. A., Gregory, J. M., Lambert, E., le Cozannet, G., Lowe, J., McInnes, K. L., Nicholls, R. J., Pol, T. D., & Wal, R. (2019). Meeting User Needs for Sea Level Rise Information: A Decision Analysis Perspective. *Earth's Future*, *7*(3), 320–337. https://doi.org/10.1029/2018ef001071

Hoffmann, E., Rupp, J., & Sander, K. (2020). What Do Users Expect from Climate Adaptation Services? Developing an Information Platform Based on User Surveys. *Climate Change Management*, 105–134. https://doi.org/10.1007/978-3-030-36875-3_7

Hu, A., & Deser, C. (2013). Uncertainty in future regional sea level rise due to internal climate variability. *Geophysical Research Letters*, *40*(11), 2768–2772. https://doi.org/10.1002/grl.50531

Hurlimann, A., Barnett, J., Fincher, R., Osbaldiston, N., Mortreux, C., & Graham, S. (2014). Urban planning and sustainable adaptation to sea-level rise. *Landscape and Urban Planning*, *126*, 84–93. https://doi.org/10.1016/j.landurbplan.2013.12.013

Ingebritsen, S. E., & Galloway, D. L. (2014). Coastal subsidence and relative sea level rise. *Environmental Research Letters*, *9*(9), 091002. https://doi.org/10.1088/1748-9326/9/9/091002

Iuorio, L., & Bortolotti, A. (2021). Integrated coastal flood design: changing paradigm in flood risk management. *The Evolving Scholar*. *14*(1), 1-7 https://doi.org/10.24404/616051311d74bb0008d549ca

IPCC. (2022). *Climate change 2022. Impacts, adaptation and vulnerability. Working group II contribution to the Sixth Assessment Report of the intergovernmental Panel on Climate Change*. Retrieved on 20th June, from: IPCC_AR6_WGII_FinalDraft_FullReport.pdf

ISO 9241-11 (2018). *Ergonomics of human-system interaction — Part 11: Usability: Definitions and concepts.* Retrieved on 25th April 2022, from: https://www.iso.org/obp/ui/#iso:std:iso:9241:-11:ed-2:v1:en

Katsman, C. A., Sterl, A., Beersma, J. J., Van den Brink, H. W., Church, J. A., Hazeleger, W., Kopp, R. E., Kroon, D., Kwadijk, J., Lammersen, R., Lowe, J., Oppenheimer, M., Plag, H. P., Ridley, J., Von Storch, H., Vaughan, D. G., Vellinga, P., Vermeersen, L. L. A., Van de Wal, R. S. W., & Weisse, R. (2011). Exploring high-end scenarios for local sea level rise to develop flood protection strategies for a low-lying delta—the Netherlands as an example. *Climatic Change*, *109*(3–4), 617–645. https://doi.org/10.1007/s10584-011-0037-5

Kerski, J.J. (2015) Geo-awareness, Geo-enablement, Geotechnologies, Citizen Science, and Storytelling. Geography on the World Stage. *Geography Compass* *9*(1), 14–26. https://doi.org/10.1111/gec3.12193

Kirchhoff, C. J., Carmen Lemos, M., & Dessai, S. (2013). Actionable Knowledge for Environmental Decision Making: Broadening the Usability of Climate Science. *Annual Review of Environment and Resources*, *38*(1), 393–414. https://doi.org/10.1146/annurev-environ-022112-112828

Kwadijk, J. C. J., Haasnoot, M., Mulder, J., Hoogvliet, M., Jeuken, A., Van Der Krogt, R. A. A., Van Oostrom, N., Schelfhout, H., Van Velzen, E., Van Waveren, H., & De Wit, M. J. M. (2010). Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(5), 729–740. https://doi.org/10.1002/wcc.64

Lawrence, J., Stephens, S., Blackett, P., Bell, R. G., & Priestley, R. (2021). Climate Services Transformed: Decision-Making Practice for the Coast in a Changing Climate. *Frontiers in Marine Science*, *8*. https://doi.org/10.3389/fmars.2021.703902

Le Cozannet, G., Nicholls, R., Hinkel, J., Sweet, W., McInnes, K., Van de Wal, R., Slangen, A., Lowe, J., & White, K. (2017). Sea Level Change and Coastal Climate Services: The Way Forward. *Journal of Marine Science and Engineering*, *5*(4), 1-27. https://doi.org/10.3390/jmse5040049

Leichenko, R. (2011). Climate change and urban resilience. *Current Opinion in Environmental Sustainability*, *3*(3), 164–168. https://doi.org/10.1016/j.cosust.2010.12.014

Lemos, M. C., Kirchhoff, C. J., & Ramprasad, V. (2012). Narrowing the climate information usability gap. *Nature Climate Change*, *2*(11), 789–794. https://doi.org/10.1038/nclimate1614

Leung, L. (2015). Validity, reliability, and generalizability in qualitative research. *Journal of Family Medicine and Primary Care*, *4*(3), 324-327. https://doi.org/10.4103/2249-4863.161306

Lourenço, T. C., Swart, R., Goosen, H., & Street, R. (2015). The rise of demand-driven climate services. *Nature Climate Change*, *6*(1), 13–14. https://doi.org/10.1038/nclimate2836

Manakhov, P., & Ivanov, V. D. (2016). Defining Usability Problems. *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems*, *7*(1), 3144-3151 https://doi.org/10.1145/2851581.2892387

McNie, E. C. (2012). Delivering Climate Services: Organizational Strategies and Approaches for Producing Useful Climate-Science Information. *Weather, Climate, and Society*, *5*(1), 14–26. https://doi.org/10.1175/wcas-d-11-00034.1

Ministerie van Infrastructuur en Waterstaat & Deltacommissaris (n.d.). *Kennisprogramma Zeespiegelstijging*. Retrieved on 25th April 2022, from: https://www.deltaprogramma.nl/deltaprogramma/kennisontwikkeling-en-signalering/zeespiegelstijging

Ministerie van Infrastructuur en Waterstaat & Deltacommissaris (n.d.). *Voorkeursstrategie Rijnmond-Drechtsteden.* Retrieved on 28th April 2022 from: https://www.deltaprogramma.nl/gebieden/rijnmond- drechtsteden/voorkeursstrategie

Ministerie van Infrastructuur en Waterstaat & Deltacommissaris (2021). Voorkeursstrategie Zuidwestelijke Delta. Retrieved on 10th December 2022, from: https://www.zwdelta.nl/strategie/voorkeursstrategie-zuidwestelijke-delta/

Ministerie van Infrastructuur en Waterstaat & Deltacommissaris (2023). *Nationaal Deltaprogramma 2023.* Retrieved on 25th April 2022, from: https://dp2023.deltaprogramma.nl

Moser, S. C., & Ekstrom, J. A. (2010). A framework to diagnose barriers to climate change adaptation *Proceedings of the National Academy of Sciences*, *107*(51), 22026–22031. https://doi.org/10.1073/pnas.1007887107

Moser, S. C., Jeffress Williams, S., & Boesch, D. F. (2012). Wicked Challenges at Land's End: Managing Coastal Vulnerability Under Climate Change. *Annual Review of Environment and Resources*, *37*(1), 51–78. https://doi.org/10.1146/annurev-environ-021611-135158

Nicholls, R. (2011). Planning for the Impacts of Sea Level Rise. *Oceanography*, *24*(2), 144–157. https://doi.org/10.5670/oceanog.2011.34

Nicholls, R. J., & Cazenave, A. (2010). Sea-Level Rise and Its Impact on Coastal Zones. *Science*, *328*(5985), 1517–1520. https://doi.org/10.1126/science.1185782

OECD. (2014). *Water governance in the Nehterlands : Fit for the future?* OECD Publishing. Retrieved on 27th March 2023, from: https://www.oecd.org/cfe/regionaldevelopment/publicationsdocuments/BrochureWaterNL%20.pdf

Pardaens, A. K., Gregory, J. M., & Lowe, J. A. (2010). A model study of factors influencing projected changes in regional sea level over the twenty-first century. *Climate Dynamics*, *36*(9–10), 2015–2033. https://doi.org/10.1007/s00382-009-0738-x

Patton, M.Q. (1999). Enhancing the quality and credibility of qualitative analysis. *Health Sciences Research*, 34, 1189–1208.

Pelzer, P. (2017). Usefulness of planning support systems: A conceptual framework and an empirical illustration. *Transportation Research Part A: Policy and Practice*, *104*, 84–95. https://doi.org/10.1016/j.tra.2016.06.019

Perrette, M., Landerer, F., Riva, R., Frieler, K., & Meinshausen, M. (2013). A scaling approach to project regional sea level rise and its uncertainties. *Earth System Dynamics*, *4*(1), 11–29. https://doi.org/10.5194/esd-4-11-2013

Port of Rotterdam: Adaptatiestrategie waterveiligheid haven van Rotterdam. Retrieved on 20th August 2022, from: adaptatiestrategie-waterveiligheid-rotterdam.pdf (portofrotterdam.com)

Raaphorst, K., Koers, G., Ellen, G. J., Oen, A., Kalsnes, B., Van Well, L., Koerth, J., & Van der Brugge, R. (2020). Mind the Gap: Towards a Typology of Climate Service Usability Gaps. *Sustainability*, *12*(4), 1512. https://doi.org/10.3390/su12041512

Raaphorst, K., Roeleveld, G., Duchhart, I., Van Der Knaap, W., & Van Den Brink, A. (2018). Reading landscape design representations as an interplay of validity, readability and interactivity: a framework for visual content analysis. *Visual Communication*, *19*(2), 163–197. https://doi.org/10.1177/1470357218779103

Rijksoverheid (n.d.). *Waterbeheer in Nederland.* Retrieved on 27th April 2022, from Waterbeheer in Nederland | Water | Rijksoverheid.nl

Runhaar, H., Wilk, B., Persson, S., Uittenbroek, C., & Wamsler, C. (2017). Mainstreaming climate adaptation: taking stock about "what works" from empirical research worldwide. *Regional Environmental Change*, *18*(4), 1201–1210. https://doi.org/10.1007/s10113-017-1259-5

Saldaña, J. (2009). *The Coding Manual for Qualitative Researchers*. SAGE Publications.

Samenwerking Klimaatadaptatie Zeeland (2021). *Klimaatadaptatiestrategie Zeeland 2021-2026.* Retrieved on 14th December 2022, from: Klimaatadaptatiestrategie Zeeland 2021-2026

Saunders, M., Lewis, P. and Thornhill, A. (2009), Research Methods for Business Students, Pearson Education, London

Scambos, T., & Abdalati, W. (2022). How fast is sea level rising? *Arctic, Antarctic, and Alpine Research*, *54*(1), 123–124. https://doi.org/10.1080/15230430.2022.2047247

Sowers, K., Ellis, R., & Dessel, A. (2010). *Literature Reviews. In The Handbook of Social Work Research Methods (Second Edition ed.)*. 55 City Road, London: SAGE Publications, Inc. Retrieved on 15th May 2022, from: https://methods.sagepub.com/book/the-handbook-of-social-work-research-methods-2e.

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change-human and Policy Dimensions*, *16*(3), 282–292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

STOWA (n.d.). *Meerlaagsveiligheid in de praktijk.* Retrieved on 16th December, from Meerlaagsveiligheid in de praktijk | STOWA

Street, R.; Parry, M.; Scott, J.; Jacob, D.; Runge, T. A. (2015). *European Research and Innovation Roadmap for Climate Services*. European Commission: Luxembourg

Thomas, D. R. (2006). A General Inductive Approach for Analyzing Qualitative Evaluation Data. *American Journal of Evaluation*, *27*(2), 237–246. https://doi.org/10.1177/1098214005283748

Tractinsky, N. (2017, May 2). The Usability Construct: A Dead End? *Human–Computer Interaction*, *33*(2), 131–177. https://doi.org/10.1080/07370024.2017.1298038

Uittenbroek, C. J., Janssen-Jansen, L. B., & Runhaar, H. A. C. (2012). Mainstreaming climate adaptation into urban planning: overcoming barriers, seizing opportunities and evaluating the results in two Dutch case studies. *Regional Environmental Change*, *13*(2), 399–411. https://doi.org/10.1007/s10113-012-0348-8

Van Der Brugge, R., Ellen, G. J., Koers, G. & Raaphorst, K. (2019). *Enhancing the value of climate data. Field trial framework for the use of knowledge concerning climate adaptation measures and their implementations*. Retrieved on 14th March 2023, from evoked-d3.1_field-trial-framework--guideline_final.pdf (ngi.no)

Van Alphen, J., Haasnoot, M., & Diermanse, F. (2022). Uncertain Accelerated Sea-Level Rise, Potential Consequences, and Adaptive Strategies in The Netherlands. *Water*, *14*(10), 1527. https://doi.org/10.3390/w14101527

Van Stigt, R., Driessen, P. P., & Spit, T. J. (2015). A user perspective on the gap between science and decision-making. Local administrators' views on expert knowledge in urban planning. *Environmental Science & Policy*, *47*, 167–176. https://doi.org/10.1016/j.envsci.2014.12.002

Van Thiel, S. (2014). *Research methods in Public Administration and Public Management: an introduction*. New York: Routledge.

Vaughan, C., & Dessai, S. (2014). Climate services for society: origins, institutional arrangements, and design elements for an evaluation framework. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(5), 587–603. https://doi.org/10.1002/wcc.290

Verschuren, P., & Doorewaard, H. (2016). Het ontwerpen van een onderzoek. Amsterdam: Boom uitgevers Amsterdam.

Vollstedt, B., Koerth, J., Tsakiris, M., Nieskens, N., & Vafeidis, A. T. (2021). Co-production of climate services: A story map for future coastal flooding for the city of Flensburg. *Climate Services*, *22*(1), 1-10. https://doi.org/10.1016/j.cliser.2021.100225

Wamsler, C., Brink, E., & Rivera, C. (2013). Planning for climate change in urban areas: from theory to practice. *Journal of Cleaner Production*, *50*(1), 68–81. https://doi.org/10.1016/j.jclepro.2012.12.008

Weaver, C. P., Lempert, R. J., Brown, C., Hall, J. A., Revell, D., & Sarewitz, D. (2012). Improving the contribution of climate model information to decision making: the value and demands of robust decision frameworks. *WIREs Climate Change*, *4*(1), 39–60. https://doi.org/10.1002/wcc.202

Williams, C. (2007). Research Methods. *Journal of Business & Economics Research (JBER)*, *5*(3), 65-72 https://doi.org/10.19030/jber.v5i3.2532

World Meteorological Organization (2022). *What do we mean by climate services?* Retrieved on 3rd April 2022, from: https://public.wmo.int/en/bulletin/what-do-we-mean-climate -services#:~:text=A%20climate%20service%20is%20a,ex-ante%20decision-making

Yin, J., Griffies, S. M., & Stouffer, R. J. (2010). Spatial Variability of Sea Level Rise in Twenty-First Century Projections. *Journal of Climate*, *23*(17), 4585–4607. https://doi.org/10.1175/2010jcli3533.1

Yin, R. (2003). *Case study research: design and methods*. London: Sage Publications

Yin, R. K. (2013). Validity and generalization in future case study evaluations. *Evaluation*, *19*(3), 321–332. https://doi.org/10.1177/1356389013497081

Appendix A: interview guide

Klimaatservice: *''Klimaatdiensten die informatie geven over klimaatverandering, klimaateffecten en klimaatadaptatiestrategieën aan besluitvormers en andere belanghebbenden. Deze informatiediensten kunnen worden gebruikt om bewustwording te creëren, het bewustzijn te vergroten of om beslissingen te nemen ten aanzien van een bepaalde klimaat issue (in dit geval zeespiegelstijging).''*

- ➔ Dit kunnen mappen, kaarten, scenario's, grafieken, infographics, rapporten of andere vormen zijn.
- ➔ Denk bijvoorbeeld aan IPCC rapport, KNMI scenario's, Klimaateffectenatlas, adaptatiestrategieën verwerkt in een rapport/document of andere (lokale/regionale) services.

Coastal Climate Core Services project (CoCliCo): CoCliCo ontwikkelt een nieuw Europees webplatform met als doel klimaatservices aan te bieden aan (lokale) besluitvormers ter ondersteuning van kustadaptatie.
Development of a new European platform on climate services for coastal risks and adaptation - Deltares

Interviewgids (Nederlands, casussen Rotterdam en Vlissingen)

Introductie

- Uitleg proces interview (incl. toestemming voor opname, opslag van de gegevens etc.)
- Definitie van klimaatdiensten voor informatie over zeespiegelstijging uitleggen
- Introductie geïnterviewde en zijn/haar verantwoordelijkheid of rol bij het beheer van de zeespiegelstijging

Effecten zeespiegelstijging

- Wat zijn de effecten van zeespiegelstijging voor de stad Vlissingen?
- Welk(e) thema('s) (zoals overstromingsrisico's, bereikbaarheid havens, verzilting, erosie, het voorzien van zoetwater etc.) worden het belangrijkst geacht met betrekking tot de zeespiegelstijging?

Informatiebehoeften

- Betreft uw rol in het zeespiegelstijging beheer, wat voor type informatie heeft u nodig om in te kunnen spelen op de toekomstige zeespiegelstijging? (bijvoorbeeld over de effecten van zeespiegelstijging of het realiseren van strategieën)
- Op welke manier verandert deze informatiebehoefte?

- Welke tijdshorizon dient te worden aangehouden wat betreft het stijgen van de zeespiegel en de effecten ervan (bijvoorbeeld 30, 50, 100 jaar)?

Klimaatservices en bruikbaarheid

- Van welke klimaatservices maakt u gebruik met betrekking tot de zeespiegelstijging?
- Welke rol heeft/hebben de klimaatservice(s) wat betreft het beheer omtrent de zeespiegelstijging?
- Hoe belangrijk is deze rol?
- Helpt de klimaatservice om tot effectief beleid te komen / doelen te realiseren?
- In hoeverre is de klimaatservice gemakkelijk en snel te gebruiken?

Factoren die (mogelijke) problemen/barrières verklaren binnen het gebruik van klimaatdiensten t.a.v. de zeespiegelstijging

- Als de klimaatservice niet voldoet aan de informatiebehoeften van de eindgebruiker, wat veroorzaakt de problematiek bij het gebruiken van de klimaatservice(s)?
  -> Doelgroep van de klimaatservice
  -> Het doel van klimaatdienst zelf
  -> Betrouwbaarheid en legitimiteit van de informatie
  -> De weergave/visualisatie van informatie
- Zijn er nog andere barrières bij het gebruik van de klimaatdienst?

Afronding interview

- Wilt u nog iets toevoegen aan dit interview?
- Samenvatting/afsluiting interview

Appendix B: Codebook

In this appendix, the coding scheme is presented. The process of coding has been done by using open coding, axial coding and selective coding. This have been done for the cases of both Rotterdam and Vlissingen.

Open coding *(Codes)*	**Axial coding** *(code group)*	**Selective coding**
Advisor SLR and policy advisor multi-layered safety at Province of Zeeland	Function respondent	Context case study
Advisor water safety at water board Scheldestromen		
Engineer at Port of Rotterdam, department Port Development		
Policy advisor multi-layered safety at Province of Zeeland		
Policy advisor water safety at municipality of Rotterdam		
Policy advisor water safety at water board Hollandse Delta		
Senior advisor network development at Rijkswaterstaat West-Nederland Zuid		
Senior advisor water safety at Rijkswaterstaat Zee en Delta		
Senior policy spatial planning & project leader at municipality of Vlissingen		
Beach erosion	SLR impacts and vulnerabilities in case studies	
Flooding		
Fresh water supply		
Function Maeslantkering		
Inner dike areas		
Outer dike areas		
Port accessibility		
Rising ground water levels		
Salinization		
Adaptatiestrategie Waterveiligheid Haven van Rotterdam	CCS used in case studies	
Delta scenarios		
Hydraulic boundaries		
IPCC report		
Kaarten Waterveiligheid		
Klimaatadaptatiestrategie Zeeland (KasZ)		
Klimaateffectatlas		
Klimaatopgaven in Kaart		
KNMI scenarios		
LIWO		
Maatregelen Waterveiligheid		
Overstroomik.nl		
Rotterdams Weerwoord		
Themakaarten Klimaat		
Zeespiegelmonitor		
Accurate/detailed information local SLR impacts/adaptation strategies	Understanding phase	SLR Information needs
Actual/recent SLR information		
Information on when and to what extent sea levels will rise		
Return period		
Simplification of SLR information for communication purposes		
SLR and spatial adaptation		
SLR impact on fresh water supply		
SLR impact on port accessibility		
SLR impact on primary flood defense		
SLR impact on sand suppletion strategy		

Costs and benefits adaptation strategies	Planning phase	
Information on feasible adaptation strategies		
Spatial themes with SLR adaptation		
Uncertainty SLR: reliability of information		
Information on costs and befits adaptation strategies	Managing phase	
Information on organizational structures / governance		
CCS based on nationally obtained data do not provide accurate information on regional/local SLR impacts	Lack of effectiveness	Usability gap CCS
CCS based on nationally obtained data not suitable for outer dike areas		
CCS based on national data not suitable for showing accurate SLR impacts		
CCS do not provide information on costs and benefits adaptation strategies		
CCS does not contain SLR information		
KNMI scenarios not suitable for creating local adaptation strategies		
Information in nationally obtained data is not recent/actual		
Lack of information on organizing SLR adaptation / governance		
Used CCS do not provide information on how to integrate spatial themes with SLR adaptation		
N/A	Lack of efficiency	
CCS often based on multiple sources	Lack of user satisfaction	
Different results in SLR information as it is updated after couple of years		
KNMI scenarios too difficult to understand		
KNMI scenarios too complex for creating awareness		
No accessibility to/knowledge about existing CCS		
Uncertainty about KNMI scenarios, lack of reliability		
CCS do not provide information on the various responsibilities SLR adaptation with regards to integrative task of dike reinforcement	Stakeholder validity	Factors influencing usability gaps
KNMI scenarios not attuned to responsibilities regarding local adaptation solutions		
KNMI scenarios too complex for local decision making	Stakeholder readability	
New CCS are needed for raising awareness		
Time horizons in KNMI scenarios hard to understand		
Interactive charts or maps needed for raising awareness	Stakeholder interactivity	
Lack of detailed information in CCS based on national data	Purpose validity	
Lack of information about outer dike areas		
KNMI scenarios not relevant when communicating risks		
Flood risks are shown but without link to SLR		
Goal KNMI scenarios is not to provide local adaptation strategies		
N/A	Purpose readability	
Purpose of Thema Kaarten Klimaat should be changed to provide SLR information in relation to given flood risks	Purpose interactivity	
Bandwidth too broad of KNMI scenarios	Information validity	
CCS mainly focus on inner dike areas, not suitable for outer dike areas		
Data sets missing in KNMI scenarios, lead to scale level issues		
Economic risks and benefits difficult to foresee		
Lack of credible SLR information: different SLR sources used in CCS leading to different results		
No awareness on existing		
No information on chance of certain scenarios		
SLR scenarios updated every couple of years, different results		
Need for understanding if application is useful for responsibility stakeholder	Information readability	
Need for understanding where data is coming from		
Unclear what information SLR scenarios provide		

Changing information to see SLR impacts or adaptation solutions could be beautiful	Information interactivity	
Changing information useful for integrating division of tasks SLR		
Integrating information on costs and benefits in interactive map is needed		
Digital CCS should be made available	Visual format validity	
New visual formats needed for creating awareness		
New visual formats needed for showing economic costs and benefits adaptation strategies		
Format of scenarios difficult to understand for local decision making	Visual format readability	
N/A	Visual format interactivity	