Managing Transitions Toward Adaptive Delta Infrastructure

A framework for improving the decision context stage

MSc Thesis

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Colophon

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Preface

This report is the result of graduation research for the completion of the Master of Construction Management and Engineering at Delft University of Technology in collaboration with Deltares. It introduces a framework to manage transitions toward adaptive infrastructure by improving the context stage of decision-making methods. Sea level rise has uncertain impacts on delta infrastructure. Therefore, the report aims to improve decision-making methods to make infrastructure more adaptive to changing conditions in the future. The issue of sea level rise as an effect of climate change, and its impacts on infrastructures and societies motivated me to study how to improve the theoretical basis of decision-making methods to develop an adaptive infrastructure.

Although the subject is complex and correlated with many disciplines and specializations, and it was difficult to find a specific venue to start from, I was excited to discover how to handle deep uncertainty regarding the sea level rise impacts on big infrastructure in unique regions like the southwest delta of the Netherlands and how to relate technical aspect with politics and socio-economic developments.

I would like to express my gratitude to the members of my graduate committee for their time and effort. I would like to thank Marcel Hertogh for his valuable supervision, constructive guidance, and support. I am also grateful to my daily supervisor Johan Ninan for his positivity, supportive help, and willingness to respond to my questions. Also, thanks to Taneha Bacchin for her valuable contribution, help and kindness. In addition, many thanks to Esther van Baaren for the opportunity to do my thesis at Deltares. I learned a lot from her expertise during the graduation journey and from her passion to work, and also appreciate her support directly and indirectly. Then, I would like to thank Noor ten Harmsen van der Beek for her supportive help, valuable comments, and contribution. Moreover, I felt very honored to be part of knowledge and research institute like Deltares for around eight months period, I express my gratitude to all members of Hydraulics for Infrastructure and Industry department and all people in Deltares and Rijkswaterstaat that I made interviews with them. Special thanks to Astrid for her valuable help since I came to the Netherlands.

Last but not least, many thanks to my wife Alaa for her love, unlimited and unconditional support in good times and bad times. Thanks to my lovely daughter Luna for being in my life, all worries vanish when I see her smiley eyes. Thanks to my family especially my father for his consistent support at every stage throughout my life. I wish to see him soon.

Mohammed Ammoun

Delft, 15 February 2023

The executive summary

Keywords: sea level rise, Eastern Scheldt, tipping points, decision making, context stage, deep uncertainty, drivers, functions.

The risk to delta regions and existing infrastructure worldwide is increasing due to sea level rise. To keep these regions safe and livable, renewal and renovation of infrastructure are essential and required. Although the Netherlands is one of the best-protected areas for flood safety, sea level rise can affect the low-lying areas where millions of people live. Flood protection, agriculture, the environment, and other aspects are affected by sea level rise and its socio-economic developments. Therefore, there is a need to re-think delta by managing the transition in conditions of uncertainty and re-evaluating the functional and technical requirements of the infrastructure.

Because of the potential consequences of sea level rise, decision-making to set adaptive strategies to handle the uncertainty over these consequences is required. There are several decision-making methods to deal with deep uncertainty and attempt to contain the impacts of sea level rise in organized response as the future unfolds. These methods are under development and need improvements to overarch challenges and strengthen the flexibility to work in different circumstances. Although each method has advantages that can be valuable and constructive in specific scopes, there are still future challenges and limitations concerning each method. Therefore, more research is required to widen the current focus and improve the applicability of the methods beyond the functional context.

<u>Objective</u>

This study aims to provide a framework to improve decision-making methods by focusing on the decision context stage and the important aspects that must be considered by decision-makers at this stage. The decision context stage is the theoretical fundamental for the methods and a signpost to steer the whole decision-making process.

<u>Questions</u>

The objective leads to the following research questions:

How to improve the decision-making context stage to deal with deep uncertainty in redesigning delta infrastructure?

1. What are the decision-making under deep uncertainty approaches (DMDU) and to what extent do they consider uncertainty over sea level rise and future states of the delta?

2. What are the different functions of the Eastern Scheldt barrier system and how are they affected by the drivers?

3. What are the steps to improve the decision context for decision-making?

The research is based on a literature review, interviews, and the Eastern Scheldt barrier as a case study. Articles about the decision-making under deep uncertainty approaches and the application of each approach are studied, especially the applications in the water management domain, which help

to determine the tipping points of the system. The semi-structured interviews were conducted with experts working at Deltares and Rijkswaterstaat who are involved in projects relevant to the Eastern Scheldt storm surge barrier. These interviews help to understand the relationships between functions and drivers that influence delta's infrastructure. Also, the Eastern Scheldt barrier as an example of delta infrastructure is included to illustrate the influence and the relationship between drivers and functions. Furthermore, the case study represents the aim of research in depth because it provides an explicit answer on how to improve the decision-making context stage. The main reason for adopting a case study in the research is to provide a specific answer to evaluate the ability of infrastructures in the delta area to be adaptive in the future.

Sub-research question 1 is related to the decision-making methods, while sub-research question 2 is relevant to the infrastructure's functions and drivers. Therefore, these two questions are answered in parallel to pave the way for the answer to the third question, which is related to improvements to the decision context stage.

1. What are the decision-making under deep uncertainty methods (DMDU) and to what extent do they consider uncertainty over sea level rise and future states of the delta?

The study focuses on three decision-making methods, Robust Decision-Making (RDM), Dynamic Adaptive Policy (DAP), and Dynamic Adaptive Policy Pathways (DAPP). Based on the literature review, a comparison between the three methods was conducted to highlight the main focus, types of actions, strengths, and weaknesses of each method. RDM has a high degree of complexity and analytic requirements, DAP depends strongly on assumptions, and the transparency of trade-offs in DAPP is not clear enough. Therefore, starting from this comparison and suggesting improvements for the decision context stage, the study analyzes the three methods in terms of 4 criteria. Political uncertainty, social uncertainty, assumptions, and tipping points. The analysis refers that RDM is less sensitive to political and social uncertainty and does not depend on the concept of the tipping point, but it is flexible in dealing with assumptions. DAP and DAPP are more sensitive to social and political uncertainty. However, DAP is less flexible to assumptions and does not depend on tipping points, whereas DAPP fulfills the four criteria. The results of studying the three methods aid to suggest improvements to the decision context stage of them.

2. What are the different functions of the Eastern Scheldt barrier system and how are they affected by the drivers?

The study depends on several tables to show how the functions of the Eastern Scheldt system will be between 2050 and 2150 in 5 states, in five different states: open, closed, moving along, seawards, and keeping on the current policy without making decisions, and under the impact of various drivers, sea level rise, socio-economic developments, and deterioration. This study shows how drivers engage in intricate and overlapping connections that make it challenging to distinguish between their impacts. As a result, drivers are categorized into three levels based on their influence and dominance. Moreover, the study illustrates how socioeconomic developments influence functions and how the functions cause socioeconomic developments in turn. These results emphasize the importance of understanding the impact of external factors on the system, and how each driver affects functionality and other drivers.

3. What are the steps to improve the decision context for decision-making?

Based on the results of the previous two questions, and the results of the interviews. The study suggests improvements to remove the limitations of the methods to develop long-term plans for adaptive infrastructure. These improvements are organized within a framework, which can be integrated into the decision context stage of the three studied methods.

The six steps to improve the decision context for decision-making methods are as follows:

zoom-in each structure in the system allows for deep evaluation of the requirements and better identification of the structure's vulnerability and opportunity

Understanding the drivers is important to determine the moment of replacement and renovation of infrastructure

More responsiveness to political and social concerns and integration of the technical components inside political and social aspects may result from the integration of the step of order the priorities into the decision context.

Consolidate investments step is essential to look for robust investments that can continue in most scenarios

Integrate life cycle management (LCM) into the context stage of DMDU methods is an opportunity to understand the functional and technical performance of structures

Define success is an essential factor to continue with the decision-making process, so it is important to achieve agreement between all stakeholders before continuing with the next stage

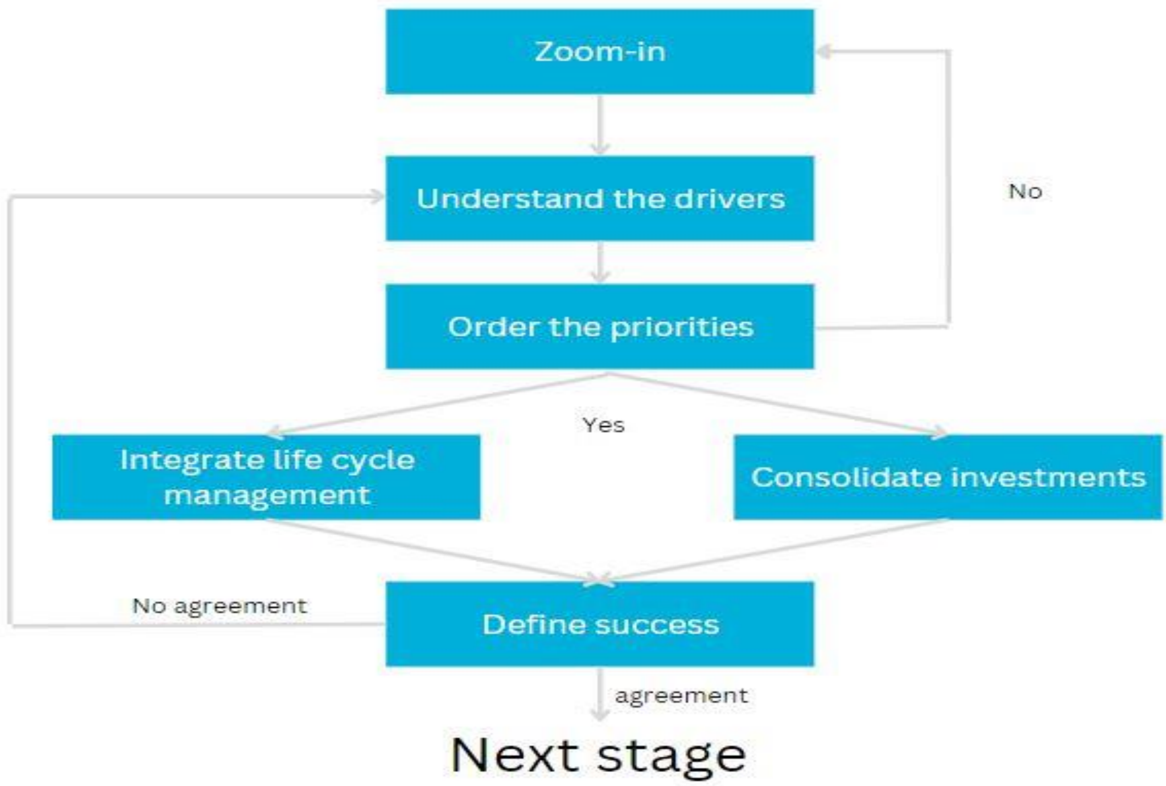

Figure 1 I. Framework to improve decision-making context

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List of abbreviations

DAP	Dynamic Adaptive Policy
DAPP	Dynamic Adaptive Policy Pathways
DMDU	Decision Making under Deep Uncertainty
EOA	Engineering Options Analysis
IG	Info-Gab decision
LCC	Life Cycle Cost
LCM	Life Cycle Management
LCP	Life Cycle Performance
LCR	Life Cycle Risk
OS	Eastern Scheldt system (Oosterschelde)
OSK	Eastern Scheldt Barrier (Osterscheldekering)
RDM	Robust Decision Making
SLR	Sea Level Rise

1. Introduction

The research introduction is divided into three subchapters that provide context for the research. Subchapter 1.1 Briefly describes the current challenges of deltas in general, the delta's current situation in the Netherlands, and the uncertainty about future scenarios. The research objective is defined in subchapter 1.2. Sub-chapter 1.3 explains the scope. The research question and sub-questions are formulated in subchapter 1.4. Sub-chapter 1.5 is the report structure.

1.1 Problem statement

Historically, the deltas have always been important places to live and trade, as there are many deltas regions in which human groups settled and established civilizations that are still alive today (Evers, 2022). Based on current reality variables such as climate change, population pressure, and the transition to a different form of energy, dealing with delta issues from a different perspective has become necessary, particularly in terms of infrastructure and how to renovate and renew delta infrastructures to become more adaptive to new changes. Furthermore, the ability to adapt to an uncertain change in functional requirements improves re-design (Sayers et al., 2021). In addition, a need has existed for innovative solutions that consider possible future scenarios such as the sea-level rise and its consequences on the surrounding environment and navigation. Despite the geographical and historical specificity of each delta around the world, complex planning challenges are common and similar. These challenges require an integrated approach that balances living, energy, mobility, nature, and agriculture in a changing landscape (Deltares, 2022). Moreover, infrastructures generally need to be more appropriate for the future economy and environment, which requires a shift of thinking of asset managers to a broader view (Hertogh et al., 2018).

Since the Netherlands is a low-lying, flood-prone country, the government aims to ensure that the country is protected against flooding and prepared for extreme weather conditions with emphasizing the importance of freshwater availability(Ministry of infrastructure and water management, n.d.). Therefore, the government set up Delta Works to protect the country against flooding and improve air and water quality. Since its completion in 1986, the Dutch delta project required many adjustments in response to challenges in water quality, nature, and freshwater. Nowadays, the dynamic character of climate change causes uncertainty for the delta infrastructure, which will be translated into effects on performance and costs, and therefore temporal losses in the functionality of infrastructures (Kenny et al., 2018). Therefore, risk and decision analysis for several scenarios depending on environmental and social aspects is required.

The delta infrastructure is a case study that requires managing transition in conditions of uncertainty. This transition, in turn, requires an approach that supports multi-scenario decision-making and multiple objectives. The decision-making process in such a complex environment involves significant risk related to conflicting goals, which makes it difficult to find a perfect solution to all problems (Shavazipour et al., 2021). Therefore, there is a need for high-level coordination among many parties, who have expertise in various fields, to measure potential risks and verify the ability of the infrastructure to be adaptable at the present and in the future. Also, plans containing a strategic vision of the future are needed, emphasizing the importance of commitment to short-term actions (Haasnoot et al., 2013a)

Figure 1 shows the different scenarios of sea-level rise and future states of the southwest area of the Netherlands. Figures on the right side represent the future states of the area, which are protected open area, closed, seaward, moving along, and other potential options. The degree of uncertainty over these future states is dependent on the sea-level rise scenarios and on the parties, who decide and formulate policy. Thus, the implementation of measures in 2050 is not necessarily effective because it is likely to cause maladaptation and disinvestment later from a long-term perspective. As a result, the timeline of transition towards a new design of the delta system is around 200 years (From 2050 to 2200-2300), the period between 2050 and 2100 is critical because the pathways and the final future state are uncertain and depend on assumptions, which also become uncertain and difficult to make over the long term (Haasnoot et al., 2013a). In other words, it is an enormous change that needs to be managed under conditions of deep uncertainty.

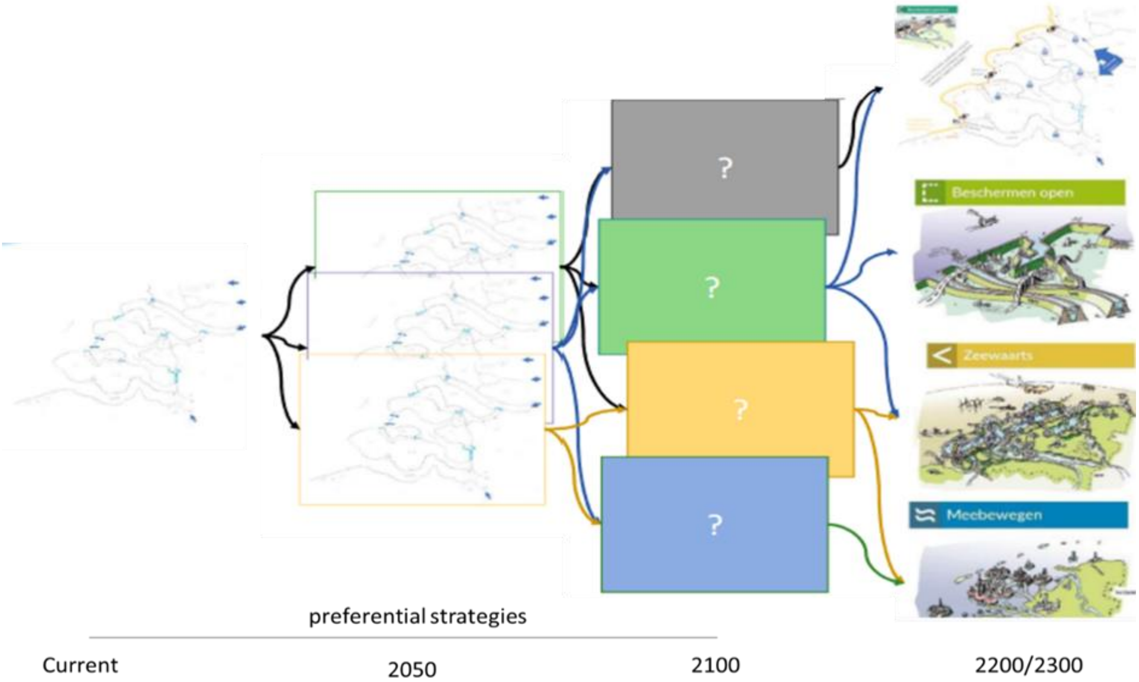


Figure 2. The transition toward a new design (van Baaren & Nolte, 2022)

Marchau et al (2019) defined deep uncertainty as a situation where uncertainty permeates some or all aspects of the problem: the system model, its outcomes, and the valuation of the stakeholders in the future. They classified the deep uncertainty into 2 levels: level A and level B. The main difference between the two levels is that level A is a situation where there are many plausible futures, whereas level B is a situation where we know that we do not know. At both levels, there is a lack of knowledge about the mechanism and relationships between components of the system, which poses a challenge for analysts to identify or specify appropriate models to represent uncertainty. Sea-level rise as part of climate change creates uncertainty for delta infrastructure and urges policymakers to rethink the delta design and infrastructure's functions. Re-think delta infrastructure as a project, requires reconsidering societal, technical, and economical contexts to produce infrastructure adaptability, which absorbs performance changes and cost effects (Auld et al., 2006). Therefore, several methods have been suggested to support decision-making under deep uncertainty. These methods are called Decision Making Under Deep Uncertainty (DMDU). Marchau et al (2019) presented in their book five methods: Robust Decision making (RDM), Dynamic Adaptive Planning (DAP), Dynamic Adaptive Policy Pathways (DAPP), Info-Gab Decision Theory (IG), and Engineering options analysis (EOA).

RDM is a set of concepts and exploratory modeling to test stress strategies over a myriad of paths under conditions of deep uncertainty (Lempert, 2019). DAP focuses on the initial plan and implementation before the resolution of all uncertainties (Walker, Rahman, & Cave, Adaptive policies, policy analysis, and policy-making, 2001). DAPP focuses on the timing of actions and generates alternative routes based on the concept of the tipping point, which focuses on under which conditions the plan will fail (Haasnoot et al., 2013a)

These methods need improvements to overarch challenges and strengthen the flexibility to work in different circumstances. Although each method has advantages that can be valuable and constructive in specific scopes, there are still future challenges and limitations concerning each method (Kwakkel & Haasnoot, 2019). Therefore, research is needed to broaden the current focus and make the methods more flexible to apply in different domains and broaden contexts, not only in a functional context. In addition, asset managers and policymakers need to integrate DMDU into life cycle management for replacement and renovation of the infrastructures to cope with future challenges, but there is still a gap because the DMDU methods are in the experience phase.

1.2 Research objective

Because of uncertainty over the sea-level rise and future states of the southwest delta in the Netherlands, this research aims to provide a framework that improves decision-making methods by focusing on the decision context stage, specifically how to organize the context stage and the important aspects that must be taken into account by decision-makers at this stage.

The research starts from specific assumptions about sea-level rise and future states. The first assumption is related to climate change and the second one depends on the policy in the future. In addition, several tipping points are considered based on the two assumptions, such as the tipping points regarding agriculture, flood protection, and the environment. These tipping points play a role in formulating the main aims of the interlinked water infrastructure networks and require measures to keep them achievable. The targeted method also should aim to introduce near-term measures that keep the system effective functionally and economically in the short term and open for modification in the long term.

Maladaptation and disinvestments can occur if the near-term actions do not consider the predictions of the sea-level rise and future states of the delta. Therefore, adaptive policymaking is needed to handle uncertainty in the long term and avoid disinvestments that can occur in the future because of wrong near-term actions. Moreover, making investments in specific structures without considering the whole system will also lead to maladaptation and disinvestments.

DMDU includes several methods and some of them are a combination of two other methods like DAPP, which is a combination of DAP and adaptation pathways method. The future challenges and weak aspects of each method are the main motivations for conducting the research, which focuses on studying three methods (RDM, DAPP, DAP). The reason behind selecting these three methods is that they have been applied in water planning contexts before. Therefore, investigating the weaknesses and strengths of these methods based on the previous applications is advantageous to make a combined method, or adopt one method with adding some improvements to handle uncertainty. Moreover, some methods like DAPP were illustrated and tested for the lower Rhine Delta, in the Ijsselmeer area specifically, it was used only for illustrative purposes and as a first tentative method (Haasnoot et al., 2013a). Therefore, the case study in this research provides a new perspective on dealing with methods and testing them within a different environment. Also, the research contributes to providing ‘prepare and adapt’ action, which does not base on a static plan to cope with specific scenarios in advance but keeps the options open to gain new knowledge and enable adaptation as far as possible.

Due to the complexity of the water infrastructure network, it is complicated to employ a methodology for the whole system. Therefore, the case study is the Eastern Scheldt storm surge barrier and the sea behind as figure 2 shows. The reason behind this selection of case study is that it represents a sub-system of the delta. The Eastern Scheldt storm surge barrier is the largest structure in delta projects, it is designed to withstand a flood situation and closes in case of 3 m above sea level. Moreover, it keeps the Eastern Scheldt sea flowable and salty which reserves nature with different animals and plants.

Figure 3. Eastern Scheldt storm surge barrier and the sea behind (google maps)

1.3 Scope

Climate change and its impacts are not confined to a specific geographical region, many regions worldwide are influenced. Therefore, it is important to define the scope of this research to determine specific areas and limitations.
Explanations of some points that determine the scope of the research are the following:

- Area: the research focuses particularly on the southwest area of the Dutch delta, considering the sea level rise for the Dutch coast. Eastern Scheldt storm surge barrier forms a case study to test the efficiency of the three methods. It is a hydraulic structure located between the Eastern Scheldt sea and the North Sea. It achieves different objectives related to agriculture, the environment, and flood protection. However, the research aim is not limited to this structure only, it is an attempt to contribute to the decision-making domain for other resembled hydraulic structures.

- Timespan: the research focuses on two timespans, the first one is until 2050, and the second one is between 2050 and 2150. The measures that can be implemented until 2050 are considered in this research as short-term measures, and measures between 2050 and 2150 are long-term. Also, the effectiveness of the short and long-term measures in the period between 2100 and 2150 is studied.

- Assumptions: the research starts from several assumptions about sea-level rise and future states of the delta area. Table 1 and Table 2 summarize the assumptions

Future states of the delta area
Open the area completely
Close the area
Move along
Seawards

Table 1. The assumption about the future states of the delta area (Deltares, 2022)

Sea level rise	
Rise per cm	Timespan
25-35	2050-2100
60-100	2100-2200
300-500	Beyond 2200/2300

Table 2. The assumption about sea level rise (KNMI, 2021)

- Boundaries: the accuracy of sea-level rise predictions is out of the scope of this research and the technical details related to hydraulic loads and flow patterns are excluded. In terms of future states of the delta that are mentioned, the options are open for proposing a new future state if the research shows a need.

1.4 Research questions

Based on the research objective and problem statement, the main question is:

How to improve the decision-making context stage to deal with deep uncertainty in redesigning delta infrastructure?

1.4.1 Sub-questions

Three sub-questions are formulated to answer the main question.

1. What are the decision-making under deep uncertainty methods (DMDU) and to what extent do they consider uncertainty over sea level rise and future states of the delta?

2. What are the different functions of the Eastern Scheldt barrier system and how are they affected by the drivers?

3. What are the steps to improve the decision context for decision-making?

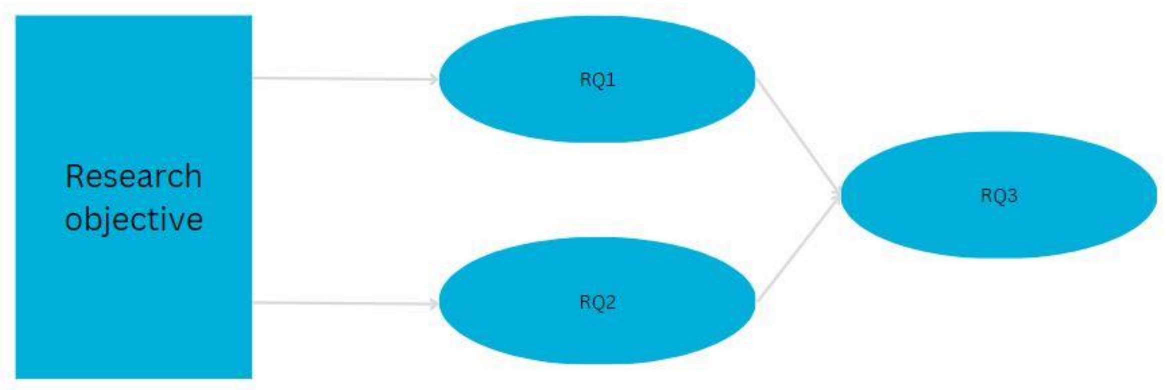


Figure 4. structure of the research questions

The answer to the first sub-question addresses the differences between the DMDU methods regarding different criteria based on the literature review and specifies which aspects of the context stage need improvements. In parallel, an analysis of Eastern Scheldt's functions and drivers aids to understand the interconnections between the components of the system. these two answers identify the key factors to improve the context stage of DMDU methods.

1.5 Report structure

Table 3 clarifies the structure of the thesis; chapter 1 is the introduction. Chapter 2 is the methodology. The findings are in chapter 3 and generate the discussion in chapter 4. Finally, all chapters lead to the conclusion in chapter 5.

Chapter 1	Introduction
Chapter 2	Methodology
Chapter 3	Findings
Chapter 4	Discussion
Chapter 5	Conclusion

Table 3. the report structure

2. Methodology

The methodology chapter provides information about the used research methods and how the data was collected and analyzed. The following sub-chapters are included: the research design (2.1), research methodology and approaches (2.2), data gathering and analysis (2.3).

2.1 Research design

The research design is shown in figure 4. Firstly, it starts with introducing decision-making methods (RDM, DAP, DAAP). Each method is checked and evaluated in its proportionality with the sea level rise, and future states of the delta, the limitations are also addressed. Secondly, the relation between drivers and functions is studied by Eastern Scheldt as a case study to clarify the influence of drivers and their importance in the context stage. Thirdly, based on the last two steps, improvements to employ the context stage effectively are suggested. Finally, the conclusions are formed based on the effectiveness of the framework in achieving the main objectives of the system and to what extent the options are open in the future.

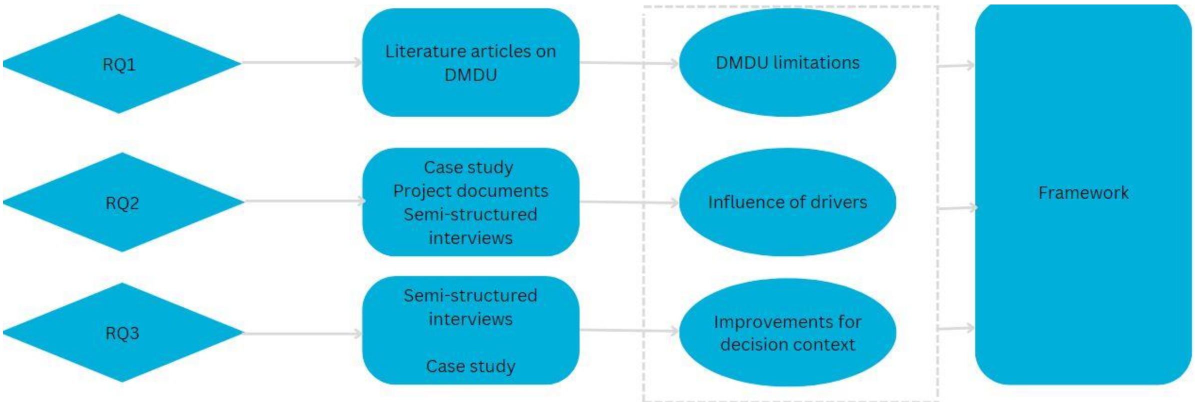


Figure 5. The research design

2.2 Research methodology and approach

The research is based on a literature review, interviews, and a case study. This section describes the three used methods that are implied together to propose substantiated conclusions.

2.2.1 Literature review

Articles about the decision-making under deep uncertainty methods and the application of each method are studied, especially the applications in the water management domain, which help to determine the tipping points of the system. Additionally, reports of Rijkswaterstaat and Deltares that are related to the delta infrastructure and how each structure interacts within the whole system are studied and analyzed.

2.2.2 Semi-structured interviews

Semi-structured interviews with experts were carried out to evaluate the improved method. The purpose of these interviews is to compare theoretical information with practical knowledge to reach more in-depth conclusions. Moreover, experts' evaluation is an important input to improve the methods. Thus, the interviews were conducted with experts working at Deltares and Rijkswaterstaat who are involved in projects relevant to the Eastern Scheldt storm surge barrier and adaptive planning projects.

Sl. No	Interviewee organization	Department	Interviewee job title	Date of interview	Duration of interview
1	Deltares	Hydraulics for infrastructure and industry	Junior advisor	7-11-2022	60 minutes
2	Deltares	Hydraulics for infrastructure and industry	Expert advisor	8-11-2022	55 minutes
3	Deltares	Hydraulics for infrastructure and industry	Expert advisor	8-11-2022	50 minutes
4	Deltares	Resilience & Planning	Expert advisor	10-11-2022	60 minutes
5	Deltares	Water resources and delta management	Senior advisor	10-11-2022	50 minutes
6	Deltares	Resilient ports & coasts	Expert advisor	14-11-2022	70 minutes
7	Deltares	Resilience & Planning	Senior advisor	21-11-2022	50 minutes
8	Rijkswaterstaat	Risks management	Senior advisor	25-11-2022	60 minutes
9	Rijkswaterstaat	Renewal & Renovation of infrastructure	Senior advisor	25-11-2022	45 minutes
10	Deltares	Coastal structure and waves	Senior advisor	29-11-2022	60 minutes
11	Rijkswaterstaat	Water management	Expert advisor (Retired)	05-12-2022	80 minutes
12	Deltares	Water resources and delta management	Advisor	12-12-2022	60 minutes

Table 4. Semi-structured interviews

2.2.3 Case study

Eastern Scheldt barrier as an example of delta infrastructure is included to illustrate the influence and the relation between drivers and functions. This case study examines how well delta infrastructure will adapt to future sea level rise. The case study also effectively illustrates the goal of the study since it offers a clear solution on how to enhance the context stage. The main reason for adopting a case study in the research is to provide a specific answer to evaluate the ability of infrastructures in the delta area to be adaptive in the future. “The case study is a research strategy in which the researcher tries to gain a profound and full insight into one or several objects or processes that are confined in time and space” (Verschuren & Doorewaard, 2010).

2.3 Data gathering and analysis

Deltares and Rijkswaterstaat are the main sources to provide reliable information about the delta system, this information is the base for determining tipping points and the planned measures. Also, they provide the assumptions of sea-level rise and future states of the southwest area.

TU Delft library, web of science, and reliable websites containing journal publications are the main sources to research in the DMDU methods. Depending on these sources and other references that are mentioned in the main articles is a useful way to explore more about the DMDU methods.

Furthermore, all the relevant data about the research case study are contained in the database of Rijkswaterstaat and Deltares, in addition to documents that are published about evaluating the current situation of the structures under research.

Lastly, carrying out semi-structured interviews with experts from Rijkswaterstaat and Deltares is a crucial source to check the data gathered and compare it with theoretical information to conclude. Moreover, interviewees' answers play a key role in reflecting improvements for the context stage of decision-making methods. Below is a list of the main questions that were asked in the interviews:

- How to make robust decisions about delta infrastructure?
- What are the challenges to setting long-term planning?
- What kind of data should be available to make a robust decision?
- Now, there are four potential future states of the delta on the table, based on your expertise, what is the expected scenario to enact?
- To what extent the socio-economic developments (number of inhabitants increases) will affect the functions of OSK?
- What are the current challenges for the DAPP method?
- DAPP can be described as a reactive method, in which aspects it needs improvements?
- To what extent RDM method is effective in the delta case?
- What is the gap between decision-making and technical evaluation?

3. Findings

In this chapter, the findings of the study are outlined. Firstly, an explanation of the uncertainty over sea level rise and future states of the delta, and their levels of uncertainty are illustrated. Secondly, decision-making methods are presented with brief explanations combined with an application for each method to illustrate the process of the methods. Sub-chapter 3.3 clarifies the comparison between the three DMDU methods as a result of the literature review and thereby answers the sub-research question 1. After presenting the DMDU methods, the role of hydraulic structures is studied in sub-chapter 3.4. It illustrates the current situation of the water management assets network and the characteristics of the system. In addition, the objectives and requirements of water infrastructure are studied to explain the degree of complexity. Sub-chapter 3.5 clarifies the four directions of the solution. The analysis in Sub-chapter 3.6 answers sub-question 2 regarding drivers' effects on the functions of Eastern Scheldt, and the potential tipping points in the four directions of solution. The answer to sub-question 3 is included in the results of the interviews in sub-chapter 3.7.

3.1 Uncertainty over sea level rise and future states of the delta

In the first chapter, it is already mentioned that the accuracy of SLR projections is out of the research's scope. However, understanding the factors that influence and accelerate the rise is essential to determine the degree of uncertainty regarding the occurrence and impacts of SLR.

SLR is driven by climate change and its results, which are melting ice sheets, temperature changes, ocean currents, and other factors (Arnell et al., 2016). The world average has risen about 20 cm in the period between 1901 and 2018 (KNMI, 2021). In terms of the Dutch coast, the local effects such as fluctuations in wind and sea currents affect the estimation accuracy of SLR close to the Dutch coast. But due to the direct connection between the North Sea and oceans, SLR will be faster in the Netherlands than the global average, and the acceleration rate will increase remarkably after 2050 especially if the Antarctic Ice sheet becomes more unstable (KNMI, 2021). Therefore, the Netherlands is one of the coastal countries that are threatened by long-term SLR. Although the Netherlands is one of the best-protected areas for flood safety, SLR can affect the low-lying areas where millions of people live.

KNMI (Meteorological institution in the Netherlands) published the annual report for 2021 which included the sea-level rise projections in 2050 and 2100 based on Co_2 emissions scenarios. Table 5 summarizes predictions and rates of acceleration of SLR in cases of optimistic, middle, and extreme scenarios of emissions.

Year	2050	2050	2050	2100	2100	2100
Emissions scenarios	Optimistic	Middle	Extreme	Optimistic	Middle	Extreme
Sea level rise in cm	14-38	15-41	16-47	30-81	39-94	54-121
Rate of ascent in mm/year	2.8-8.7	5.2-10.6	5.8-12.1	2.9-9.1	4.4-10.5	7.2-16.9

Table 5. Indicative sea level scenarios for the Dutch cost (KNMI, 2021)

SLR as a consequence of climate change has in turn economic and social consequences in the short and long terms. In the long term, the uncertainty degree becomes higher not only because of the accuracy of how many centimeters will the sea level rise but in other contexts that are deeply related to decision-making. Currently, the discussion of whether global climate change is taking place or not is largely removed (Cook et al., 2013). The discussion currently is about the growing uncertainty over related aspects that Hallegatte (2009) summarized as follows:

- The magnitude of climate change and how the future scenarios consider the increased average temperature differences.
- The speed of climate change and the speed of policy actions.
- The impacts of climate change on specific areas around the world. For example, the impacts of sea level rise on countries like the Netherlands are larger than in countries like Romania.
- The policies that should be formulated to face (mitigate or/and hedge) the consequences of climate change.

These four aspects lead to conclude that the uncertainty is not about the occurrence of climate change but about how its consequences will change the current situation, and what policies can be taken. Moreover, how the policymakers will handle the consequences of climate change in case of constraints regarding budget, political circumstances, and national priorities? Therefore, the correlation between sea level rise and policies that should be implemented is complicated and can be described as independent somewhere. There are two types of policies regarding SLR, the first type is the responding policy which includes actions or investments depending on what will happen as a consequence of SLR. while the second policy is formulated to achieve different goals unrelated to SLR, this rise could be a challenge for the results of the policy in the future.

The future states of the delta that are mentioned in the previous chapters are: open the area, close the area, moving along, and seawards. These states depend on policies drawn by decision-makers who do not necessarily consider SLR as the main reason or aim behind the policy. The government could probably implement a policy to achieve the interests of a particular party within a socio-economic development plan without serious thinking about the SLR consequences of this policy in long term. Therefore, we are in front of anticipated or known events, that are SLR scenarios, but we do not know what are the policy responses to these scenarios and the role of policymaking in the storyline of uncertainty (Haasnoot et al., 2013). Here the importance of adaptation emerges because the static plan to deal with what the future unfolds is not efficient (Yohe, 1990). One more point, decision-making under deep uncertainty is not only over future states of a specific situation, it is also related to the strategic behavior of the stakeholders (Quade, 1989), i.e., if one party has interests today, it does not mean that the same interests will remain tomorrow. It is important to recognize that upgrading and renewing infrastructure are a decision more than a technical issue unless the infrastructure has collapsed and cannot be maintained (Hertogh et al., 2018). Therefore, uncertain external factors can play a key role in decision-making.

Uncertainty has a range of levels depending on the degree of knowledge. Donald Rumsfeld[1] has a famous saying:

'' As we know, there are known knowns – these are things we know we know. We also know there are known unknowns – we know there are some things we do not know, but there are also unknown unknowns – the ones we don't know we don't know.... It is the latter category that tends to be the difficult one''.

Walker et al (2003) define four levels related to knowledge assumed about four aspects of a problem, the future state of the world, the model of the relevant system for that future world, the outcomes of the system, and the stakeholders' wights that will be put on the outcomes.

[1] Donald Rumsfeld, Department of Defense News Briefing, February 12, 2002.

The knowledge gap in each level of these previous four levels determines the uncertainty degree and to what extent the uncertainty permeates problem aspects. The levels of uncertainty are also categorized into four levels as follows (Marchau, Walker, Bloemen, et al., 2019) :

- Level 1: the system is well-defined and historical data can be used as predictors of the future. Generally, this level of uncertainty requires short-term decisions because the outcomes are predictable, and model input parameters are assessed. For example, mail delivery and garbage collection.
- Level 2: the system and its model inputs can be described probabilistically, which means that model parameters describe the stochastic properties of the system. At this level, the effective policy is chosen based on the expected outcomes and levels of acceptable risks. Deciding on which line to join in a supermarket is a problem that belongs to level 2.
- Level 3: there is a limited set of plausible futures, system models, and probabilities that cannot be assigned to them. Traditional scenario analysis can be used in cases of this level. This analysis can predict the future to identify policies that lead to acceptable outcomes in a few specific scenarios. It is important here to distinguish between two questions: what will happen? and what can happen? the scenario analysis is used to answer the second question. Therefore, a static policy plan that produces an acceptable outcome is the best at this level. For example, leaving an umbrella in the car in case of rain is an approach to address level 3.
- Level 4: is the deepest level of uncertainty and it is divided into two levels: A and B. Level 4A is a situation where we can bind the future around many scenarios. Whereas level 4B is a situation where we just know that we do not know as Rumsfeld said. At this level, models that can describe the interactions between the system's variables are difficult to specify. Table 6 illustrates the four levels of uncertainty based on the context, system model, system outcomes, and stakeholders' weights.

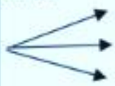
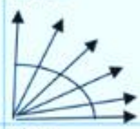
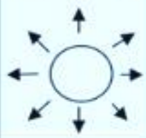
	Complete determinism	Level 1	Level 2	Level 3	Level 4 (deep uncertainty)		Total ignorance
					Level 4a	Level 4b	
Context (X)		A clear enough future 	Alternate futures (with probabilities) 	A few plausible futures 	Many plausible futures 	Unknown future 	
System model (R)		A single (deterministic) system model	A single (stochastic) system model	A few alternative system models	Many alternative system models	Unknown system model; know we don't know	
System outcomes (O)		A point estimate for each outcome	A confidence interval for each outcome	A limited range of outcomes	A wide range of outcomes	Unknown outcomes; know we don't know	
Weights (W)		A single set of weights	Several sets of weights, with a probability attached to each set	A limited range weights	A wide range of weights	Unknown weights; know we don't know	

Table 6. The progressive transition of levels of uncertainty (Marchau, Walker, Bloemen, et al., 2019)

From the table, it is obvious that decision-making for a transition toward adaptive infrastructure does not match the properties of levels 1 or 2 because the contexts and system models of these two levels are simple and never represent the complexity degree of transition variables. Also, the method to handle uncertainty in level 3 assumes that a few scenarios can be specified to formulate policies and produce acceptable outcomes. It is a traditional method that has been used in the past, but the main negative aspect of this method regarding the transition toward adaptive infrastructure is that it depends completely on assumptions. If these assumptions about the future turn out to be wrong, the losses and disinvestments will be unaffordable because the static policy will not be able to deal with the new dynamic situation. Moreover, uncertain conditions of SLR and future states permeate all four aspects that are included in table 5. There is uncertainty about the final state at present time, and the appropriate system in the future is unknown. Also, external development plays an important role, and consensus about the outcomes between stakeholders is not obvious. Furthermore, the transition toward adaptive infrastructure requires preparing and adapting strategy, which allows adaptations over time and recognizes long-term developments. This strategy is a requirement of decision-making under deep uncertainty (Level 4), while levels 1,2, and 3 are based on predictions of the future without considering dynamic changes.

3.2 Decision-making under deep uncertainty methods

Many methods for decision-making under deep uncertainty have been developed in the last few years, and applications of DMDU often involve cycling through iterative loops. However, the order of the elements and steps in these loops is not strict (Marchau, Walker, Bloemen, et al., 2019). This means that a generic set of elements can be made as a template that represents all the mutual steps and tools of DMDU in the research.

Figure 5 represents the general elements and steps of DMDU:

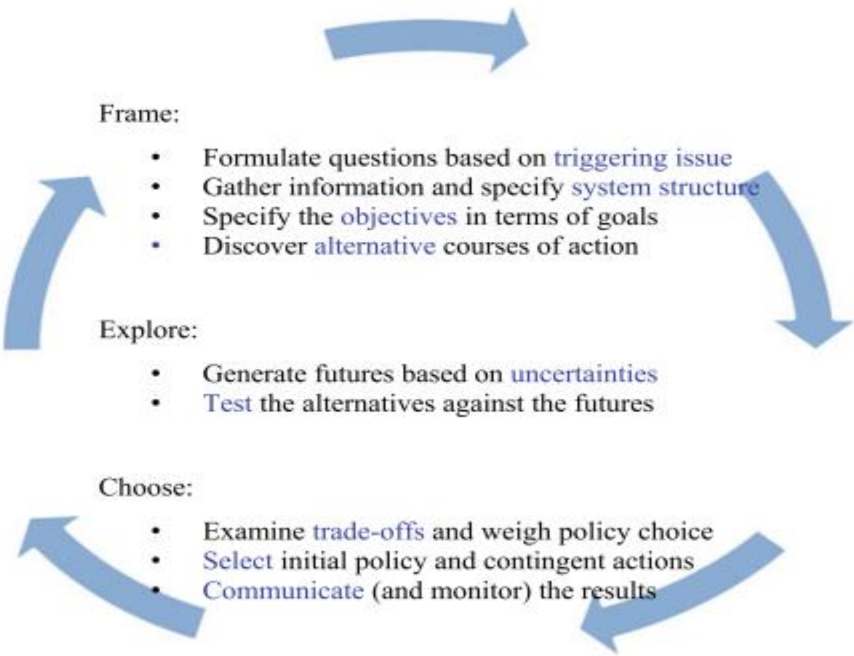


Figure 6. Elements and steps of DMDU methods (Marchau, Walker, Bloemen, et al., 2019)

Frame means specifying the system structures, constraints, objectives, and policies. Explore means specifying uncertainties about the system, outcomes, and valuation of these outcomes. Also, generating alternatives and testing them against the future. Choose step considers the trade-offs and selects the initial policy. Then monitoring the results (possible adaptations) of the policy.
As mentioned in the first chapter, the research focuses on the context stage, which is the basic stage from which decision-making begins, through which the goals of the system to be decided are

identified and understood, in addition to their necessity to assess the robustness of solutions in the future. In the next subchapters, the three methods are presented for more clarification.

3.2.1 Robust decision-making (RDM)

Robust decision-making (RDM) consists of concepts, processes, and enabling tools that depend on computation to yield better decisions under conditions of deep uncertainty. RDM method combines decision analysis, Assumptions based planning, Exploratory Modelling, and scenarios to test strategies over many paths into the future. Then policy-relevant scenarios and robust adaptive strategies are identified(Lempert et al., 2003).

Lempert et al (2003) pointed out four key elements of the RDM method. Firstly, seek robust rather than optimal strategies. Robust strategies perform better compared to the alternatives over a wide of plausible futures. Secondly, Consider the multiplicity of plausible futures. Thirdly, use the computer to facilitate human deliberation over explorations and tradeoffs, not as a recommender for particular strategies. Fourthly, employ adaptive strategies to reach robustness. Adaptive strategies are designed to respond to new information as the future unfolds.

3.2.1.1 Robust decision-making (RDM) process

The RDM process does not guide how to address the identified vulnerabilities in designing strategy but it only describes the steps to identify vulnerabilities and tradeoffs (Kwakkel, Haasnoot, et al., 2016). Figure 6 shows the main steps of the RDM process.

Step 1 as shown in the figure is defining the key factors, strategies, and objectives based on stakeholders' inputs. In addition, decision-makers as part of stakeholders introduce their objectives and possible actions to achieve these objectives. The actions, in turn, have consequences. Uncertainties may affect the relationship between the actions and consequences. Therefore, computer simulation models instantiate the uncertainty that affects the relation between actions and objectives (Marchau, Walker, Bloemen, et al., 2019). Step 2 is using simulation models to evaluate proposed strategies in many plausible futures, which generates a database of simulation model results. Step 3 depends on the database that is produced in step 2 to explore and characterize vulnerabilities by analysts and decision-makers. RDM analyses use statistical Scenario Discovery (SD) algorithms to identify and display for users the key factors that best distinguish futures in which proposed strategies meet or miss their goals(Marchau, Walker, Bloemen, et al., 2019). After identifying the vulnerabilities in step 3, analysts and decision-makers evaluate tradeoffs between strategies and competing objectives to identify more robust strategies.

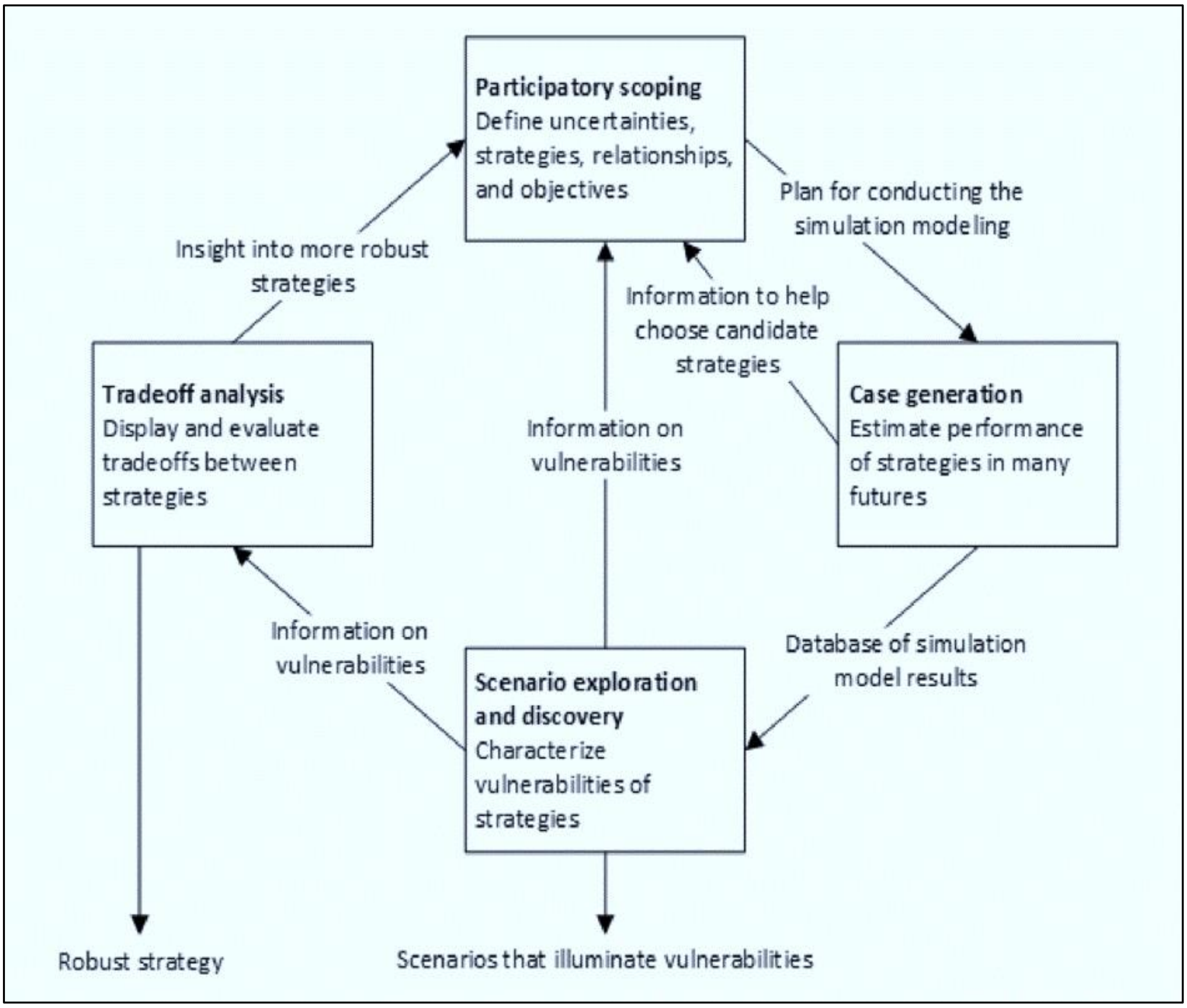


Figure 7. The RDM process (Lempert et al., 2003)

3.2.1.2 application of RDM

One of the applications of RDM is Colorado River Basin, where the RDM method was adopted to support long-term water resources planning. The Colorado River is the largest source of water in the southwestern USA, it provides water and power for more than 40 million people, in addition to other functions like irrigation and agricultural needs to Mexico (Bureau of Reclamation, 2012). The management system consists of 12 major dams, and major infrastructures that transport water from the Colorado River and its tributaries to Colorado's Eastern Slope, Central Arizona, and Sothern California.

The problem started when the reliability of the system has been increasingly threatened because of the increasing demand for water and the uncertainty over future suppliers. (Melillo, Richmond, & Yohe, 2014). In addition, the estimates of future streamflow based on records and models suggest a wide range of future hydraulic conditions, many of which would be drier than recent conditions(Bureau of Reclamation, 2012). Therefore, the US Bureau of Reclamation and the seven basin states initiated the Colorado River to meet water needs and other objectives across a range of futures (Bureau of Reclamation, 2012).

The Basin study adopted RDM to achieve or keep on different objectives, including water supply reliability, hydropower production, ecosystem, and recreation by identifying the system vulnerabilities and evaluating different management actions that can be taken based on the evolving conditions. And lastly, tradeoffs between water system reliability and the cost of management actions are defined.

After describing the problem of the Colorado Basin briefly, a summary of the RDM steps in Figure 6 is presented in a practical context starting from scoping and defining the vulnerabilities as follows:

- Scoping

Objectives of the water management system: 1. The 10-year running average of water flow from the upper to lower Basin should meet or exceed 7.5 maf per year, that is called the upper Basin reliability objective. 2. Maintaining Lake Mead's pool elevation above 1000 feet, which is called lower Basin reliability.

- Vulnerabilities:

After eight years of drought with average flows below 13 maf, the lower Basin is therefore vulnerable, and it is called low historical supply because it depends on the historical record. While the upper Basin is vulnerable to declining supply. This vulnerability depended only on future projections

- Case generation

The study evaluated a range of hydraulic conditions, some of them depended on historical and paleoclimate records and others on projections. The hydraulic conditions were combined with six demand scenarios and two operation scenarios to define 23,508 unique futures. The study also used Reclamation's long-term planning model – the Colorado River Simulation System (CRSS) to evaluate the system under different futures. CRSS simulates operations at a monthly time step from 2012 to 2060 and models the network of rivers and 12 reservoirs.

- Scenario exploration and discovery

Stakeholders defined 4 portfolios; each one includes a different set of investments for implementation. Portfolio B includes investments focus on reliability focus, portfolio C includes investments focus on environmental performance, Portfolio A includes all investments in either C and B, and finally, portfolio D includes only investments in both B and C. Based on these portfolios, some strategies are generated: two static strategies (Current management and implement all actions) and two adaptive strategies (Baseline strategy and aggressive). For example, the aggressive strategy represents stakeholders and planners with different preferences for cost and reliability.

- Tradeoff analysis

A robust strategy in this case study is defined as one that minimizes regret across a range of plausible future conditions. Regret is defined as the additional amount of water that is needed to maintain the Lake Mead level at 1000 maf. The outcomes show that the two static strategies have the highest regret in the high streamflow conditions, while the two adaptive strategies are more balanced and have low regret.

3.2.2 Dynamic adaptive planning (DAP)

DAP aims to implement an initial plan before the resolution of all uncertainties, considering adaptations over time based on new knowledge. DAP specifies the development of a monitoring program and responses when specific trigger values are reached. Therefore, adaptation over time is included in a plan formulation by DAP. DAP is implemented in two phases:

1. the design phase, which includes: a dynamic adaptive plan, a monitoring program, and several pre- and post-implementation actions.

2. the implementation phase, in which the plan and the monitoring system are implemented and contingent actions are taken (Walker et al., n.d.). Figure 7 shows the steps of DAP

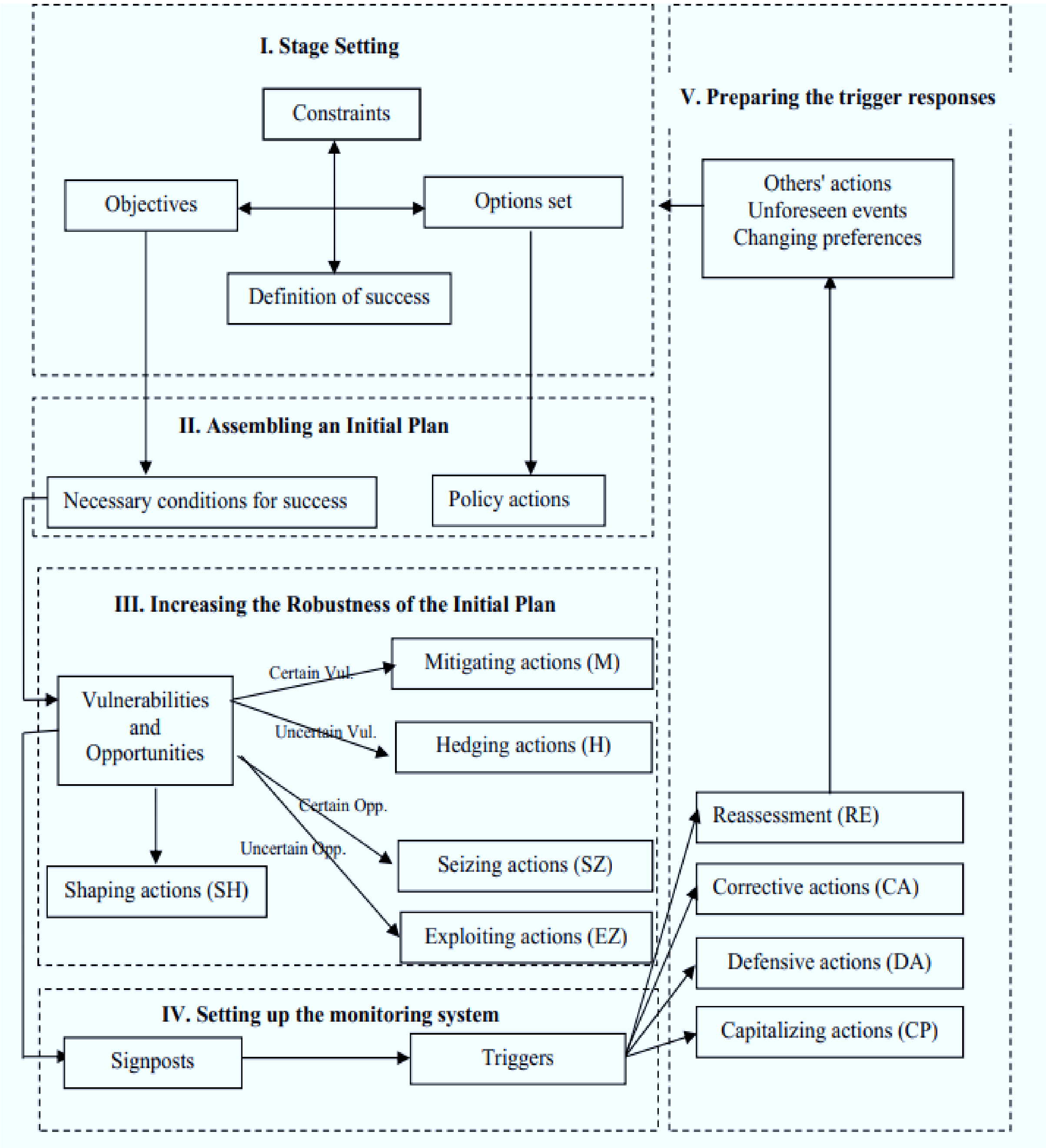


Figure 8. the steps of the DAP method

In the stage, I, the objectives and set of options that are important to planners and stakeholders are defined, in addition to the constraints of achieving the objectives and how all parties define success. Stage II includes the necessary conditions for success and policy actions as an initial plan. Stage III is about increasing the robustness of the initial plan, some vulnerabilities can diminish the success of the initial plan, and opportunities increase the success of the plan. To increase the robustness of the initial plan, five types of actions can be taken to address the vulnerabilities and opportunities, which are (Walker et al., 2013)

- Mitigating actions (M) reduce impacts on a plan stemming from certain vulnerabilities
- Hedging actions (H) reduce impacts on a plan or reduce risks that stem from uncertain vulnerabilities
- Seizing actions (SZ) take advantage of certain opportunities that may prove beneficial to the plan
- Exploiting actions (E) take advantage of uncertain developments that can make the plan more successful
- Shaping actions are taken proactively to affect external events that could either reduce the plan's chance of failure or increase the chance of success (Walker et al., 2019).

Step IV is setting up a monitoring system that will inform decision-makers about actions that can be taken in response to new conditions, which gives the flexibility to adapt to new conditions over time. The monitoring system consists of triggers and signposts that help to determine if the initial plan is currently achieving its objectives or not.

Stage V focuses on the contingent actions that can be taken in case of trigger event occurs over the life of the plan. Walker et al (2013) divided contingent actions into four types:

- Defensive actions (DA) are taken after implementation of the initial plan to clarify the plan and preserve its benefits but they leave the plan unchanged
- Corrective actions (CR) are adjustments to the initial plan in response to specific triggers.
- Capitalizing actions (CP) taken after implementation of the initial plan to take advantage of opportunities that improve the initial plan.
- Reassessment (RE) is a process when unforeseen events cause a fundamental change in the assumptions and objectives of the initial plan.

That is the theoretical basis of the DAP method, it provides in advance various action types to deal with vulnerabilities that can be emerged because of uncertainty. these theoretical steps are more elaborated in the next sub-chapter with an example of DAP application in the traffic field.

3.2.2.1 Application of DAP

DAP has been adopted in several applications like flood risk management and policies of innovative urban transport infrastructures. In this subchapter, the application in transport is presented because it is more understandable and abbreviated.

ISA is an in-vehicle system that helps the driver to comply with the legal speed limit at a certain location, it depends on the functions of systems that are already available in most vehicles (GBS and engine management systems).

To avoid complexity in details and long tables. The tables below present one element of each stage as an illustrative example. Table 7 shows stages I and II, Table 8 is step III, and finally, table 9 summarizes stages IV and V.

The Complete tables with all details of the DAP application are included in Appendix A.

Initial plan				
Type of driver	Type of ISA	Action	Definition of success	Constraints
Phase I (2009-2012)				
Complaint driver	Warning ISA (Speed Alert)	- Start a campaign aimed at persuading people to turn on the speed alert functionality on their navigation device. - Make agreements with companies that develop navigation devices	Before 2013: 50% of the people that own and use a navigation device actively use the speed alert functionality	Budget for a campaign

Table 7. stages I, II (Marchau, Walker, & van der Pas, 2019)

Three types of drivers are determined in the application, compliant drivers, less compliant drivers, and notorious speed offenders. Each type requires a specific type of ISA, action, definition of success, and constraints. Table 7 illustrates the compliant driver type and what are the actions and constraints of this type of driver.

Vulnerabilities (V) and opportunities (O)	Hedging (H), Mitigating (M), Seizing (S), and Exploiting (E) actions
V: The availability of an accurate speed limit database. Speed limit data have to be correct for the right time (dynamic), the right location, and the right vehicle.	M: Define and apportion responsibilities before starting with implementation. M: Issue a request for bids for the development of a speed limit database (this should be arranged by public authorities) M: Guarantee quality through a third party that is under the supervision of the public authorities M: Develop a system based on beacons that overrule the static speed limit information (fail-safe design)
O: Cars and ISA draw lots of attention and appeal to people's emotions. Instead of seeing this as a threat, this can be used as an opportunity	S: Invite stakeholders that have positive feelings about ISA to participate in improving and implementing ISA (e.g., the presenters of Top Gear, race drivers)

Table 8. Stage III (Marchau, Walker, & van der Pas, 2019)

In stage III, vulnerabilities and opportunities are defined. Table 8 demonstrates one vulnerability and one opportunity as examples. In the right column, mitigating and seizing actions are mentioned to deal with vulnerability and opportunity.

Vulnerabilities (V) and Opportunities (O)	Monitoring and triggering system	Actions: Reassessment (R), Corrective (CR), Defensive (D), and Capitalizing (CP)
V: The availability of an accurate speed limit database. Speed limit data have to be correct for the right time (dynamic), the right location, and the right vehicle.	Monitor the Level of accuracy/reliability of the speed limit database	D: Initiate database accuracy enhancement CR: Stop implementation of certain types of ISA or combine with on/off switch and overruling possibilities CR: Design the system in such a way that it only warns/intervenes in areas with certain accuracy levels

Table 9. stages IV, V (Marchau, Walker, & van der Pas, 2019)

Table 9 clarifies how to monitor and take corrective actions for the vulnerability that is mentioned in table 8. Monitoring the level of accuracy and reliability of the speed limit database aids to determine the direction of the corrective actions. Therefore, the accuracy and reliability of the database are triggers to improve.

The tables above explain some steps that are implemented in the DAP application. They illustrate the connection with the first stage and how this stage steers the direction of the solution because the constraints and definition of success are defined from stage I. stage III specifies the vulnerabilities and opportunities based on the definition of success that is defined in stage I. stage IV, V include the monitoring and triggering system as a tool to determine to what extent can the system work under constraints influence.

3.2.3 Dynamic adaptive policy pathways (DAPP)

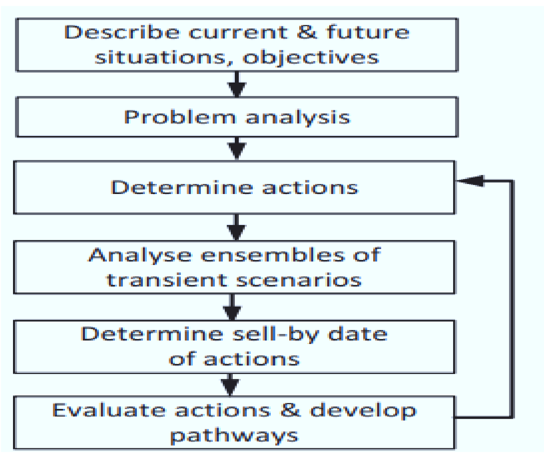


Figure 9. Stepwise policy analysis (Haasnoot M. , Kwakkel, Walker, & ter Maat, Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world, 2013)

DAPP focuses on the timing of actions and produces an overview of alternative paths in the future. The paths depend on the Adaptation Tipping Points (ATPs) method, which focuses on '' under which conditions will the plan fail''(Haasnoot et al., 2013).

DAPP is based on complementary methods for designing adaptive plans: Adaptive policymaking and adaptation pathways. Adaptive policymaking is the same method of dynamic adaptive planning DAP, that is already explained in the previous subchapter. The adaptation pathways method focuses on the conditions where an action no longer meets the specified objectives, that is called tipping points of the system. As a result, additional actions are needed to deal with reaching the tipping point. Therefore, the adaptation pathway emerges and contains a sequence of possible actions (Haasnoot et al., 2013)

The adaptation pathways were drawn based on model results or expert input that present an overview of relevant pathways (Haasnoot et al., 2013). Figure 8 shows the stepwise policy to construct adaptation pathways. Moreover, figure 9 presents an example of an adaptation pathway map with different signs and colors specified for 5 actions. Next to the map, there are scorecard pathways that present costs and benefits for each pathway.

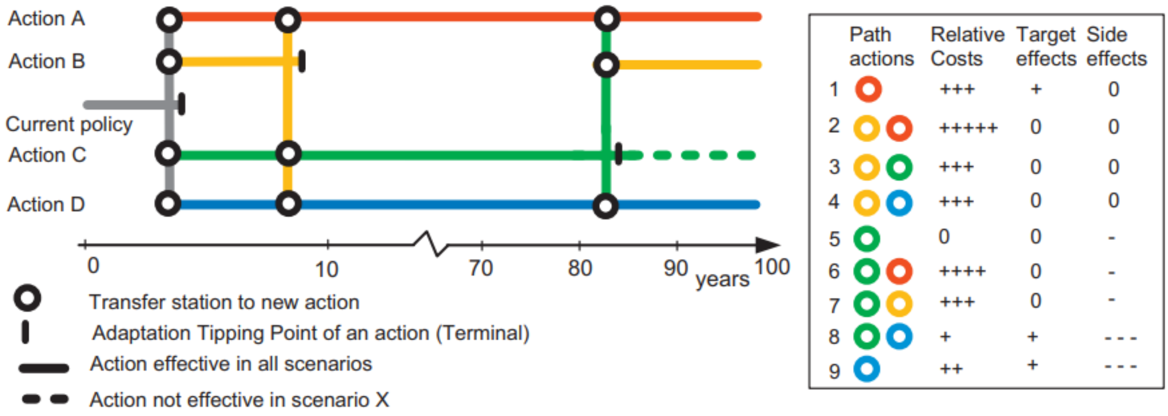


Figure 10. Adaptation pathways and scorecard (Haasnoot et al., 2013)

Haasnoot et al (2013) compared the two methods DAP and adaptation pathways to find the intersected steps and the main differences (see table 10)

Aspect	Adaptive Policymaking	Adaptation Pathways
Focus	Starts from a vision of the decisionmaker and creates a plan for realizing this vision and protecting it from failure.	Explores actions for achieving objectives over time by including dynamic interaction between the system and society.
Consideration of the multiplicity of futures	Indirectly via vulnerabilities and opportunities.	Explicitly via transient scenarios.
Planning process	Comprehensive stepwise approach for designing a plan.	Short stepwise approach for designing Adaptation Pathways.
Clarity on how to design a plan	Limited; a high level framework that can be translated into a specific plan in many different ways.	Application oriented, with a clear link to the use of models to develop a specific plan.
Types of actions that can be taken	Distinguishes many different types of actions that can be taken (e.g. hedging, mitigating, and shaping).	No specific categorization of actions is used. Several actions and pathways are presented. A variety of actions are identified based on different societal perspectives.
Desirable plan	One basic plan is developed. No clear guideline on how develop the basic plan.	Several pathways are presented. Different perspectives result in different preferred pathways. No focus on how to identify promising pathways when confronted with a large number of possible actions.
Consideration of types of uncertainties	In principle, any uncertainty can be accounted for.	In principle, any uncertainty can be accounted for. Explicit attention is given to social uncertainty.
Flexibility of resulting plan	Flexibility is established through the monitoring system and associated actions.	The Adaptation Pathways map clearly specifies when a policy should be changed, and what the next action should be.
Dynamic robustness of resulting plan	Dynamic robustness results from the monitoring set up in Step IV and the actions taken in Step V.	Dynamic robustness is produced indirectly via the idea of a 'sell-by date' and the shift to another action.

Table 10. Comparison of the methods

The combination of adaptive policymaking and adaptation pathways is called Dynamic Adaptive policy Pathways, it results from using the strengths of both methods. Figure 10 shows the resulting method DAPP.

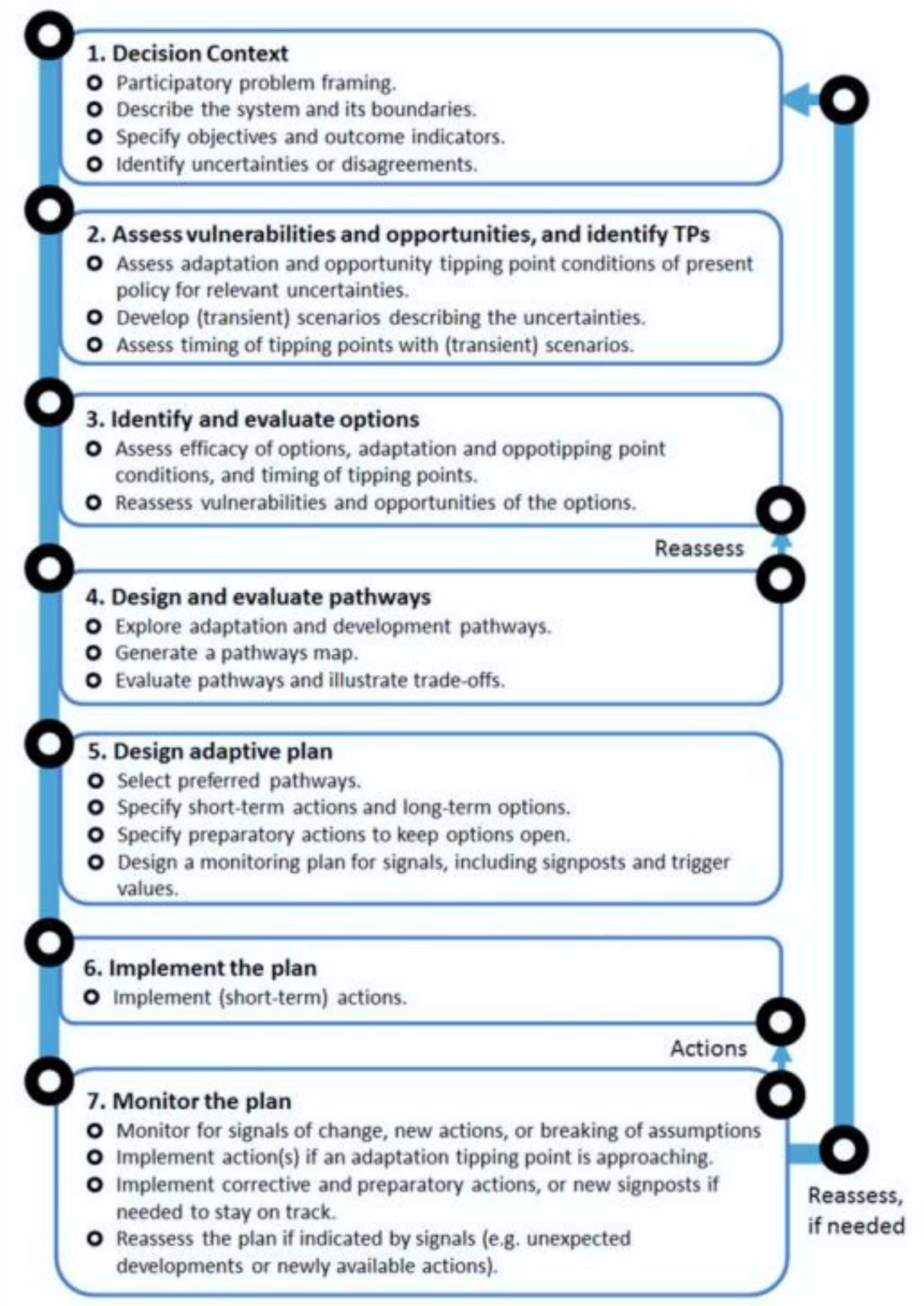
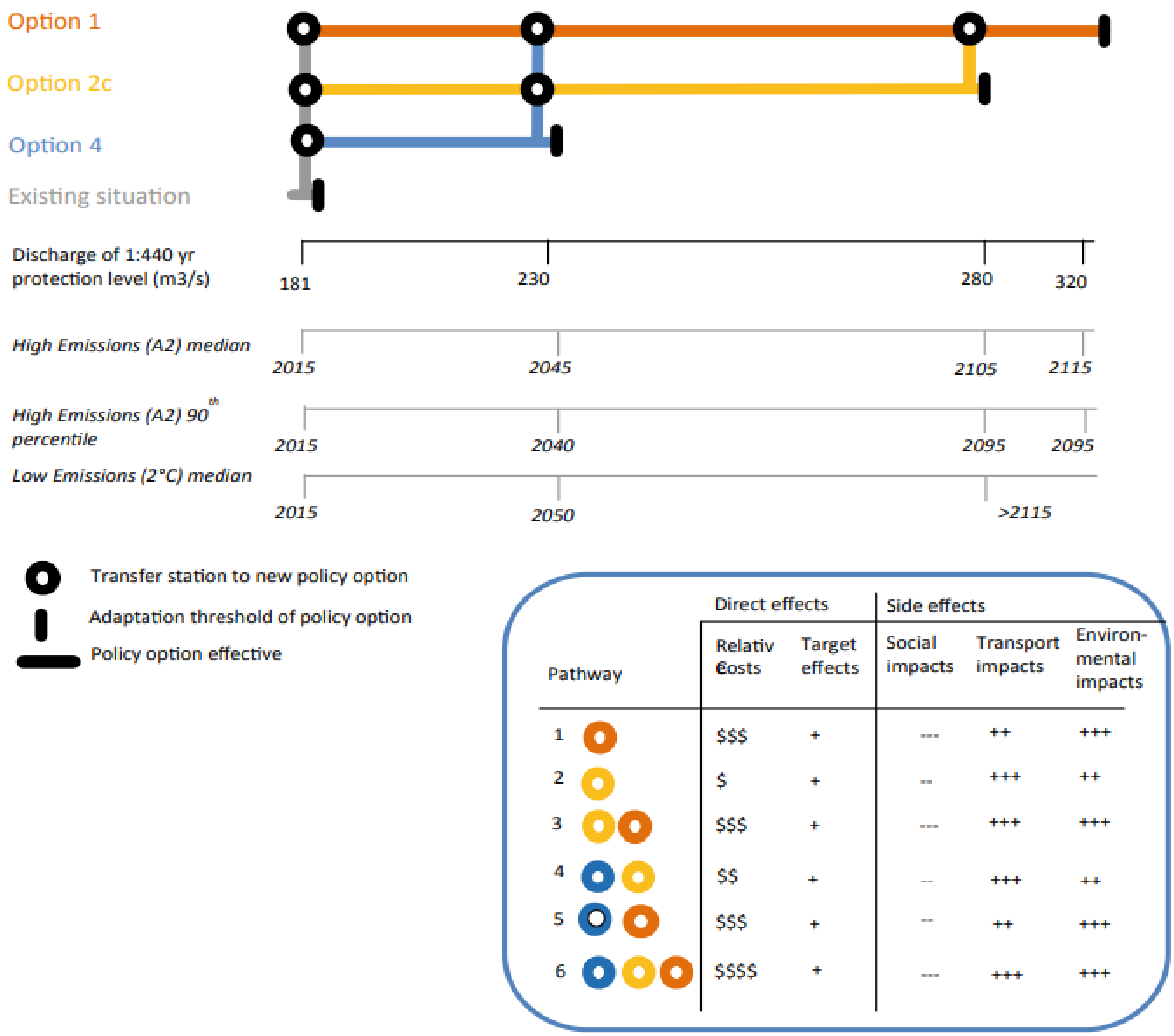


Figure 11. DAPP method adopted by Haasnoot et al (2013)

3.2.3.1 Application of DAPP

This subchapter describes how DAPP is applied in flood risk management in New Zeeland. Briefly, flood managers in New Zeeland built large structural works in the past to manage flood risk in river catchments. The works were designed based on assumption that the future will be like the past. But in the last decades, it has been obvious that long-term land-use development planning has not considered climate change. The objective is to protect Wellington city for at least 100 years from the 1:440-year flood event (Lawrence et al., 2019).

Figure 11 illustrates the results of applying DAPP to the case.



Relative impacts are indicated with – and +; - is negative impact and + positive impact. All pathways have negative social impacts, as land has to be purchased. (Option 1: A 90m river channel and 50 m berm; right and left stopbanks meets the standard over 100 years in all scenarios; cost $267m. Option 2C: A 90m river channel 25 m berm; properties to be purchased; cost of $143 million. Option 4: 70 m river channel; 30 years of flood protection; lower level of protection (2300 m3/s); properties purchased after 20 years; cost $114m until 2035. Staged Option 4 to Option 2C will cost an additional $68 million; total cost $182.m million).

Figure 12. Hutt River City Centre Upgrade Project: adaptation pathways map showing options, pathways, scenarios, and adaptation thresholds; scorecard showing relative costs and direct effects of pathways, and potential side effects requiring consideration (Lawrence, et al., 2013).

Stakeholders and community supported the option 2C and Council decided to implement this option. Although option 2C was not the most cost-effective, it was chosen because certainty was the motivator.

3.3 comparison

	RDM	DAP	DAPP
Main focus	- Consider a multiplicity of plausible futures (Walker et al., 2013) - Seek robust rather than optimal strategies (Lempert et al., 2003)	Protecting the initial plan from failure (Walker et al., 2019)	addressing deep uncertainty by considering the long-term effects of initial decisions on changing conditions (Haasnoot et al., 2013; Kwakkel, Haasnoot, et al., 2016)
Types of actions	No specific categorization of actions	Different types of actions can be taken	Different types of actions can be taken
Strengths	- Makes trade-offs transparent (Kwakkel, Haasnoot, et al., 2016)	- It forces planners to consider changes continuously (Marchau, Walker, & van der Pas, 2019)	A dynamic adaptation over time (Kwakkel, Walker, et al., 2016)
Weaknesses	- The complexity and analytic requirements - Time - Iterative (Groves et al., 2019; Kwakkel, Haasnoot, et al., 2016)	- Lack of examples (Marchau, Walker, & van der Pas, 2019) - Depends strongly on assumptions (Marchau, Walker, & van der Pas, 2019)	Trade-offs transparency (Kwakkel, Haasnoot, et al., 2016; Shavazipour et al., 2021)

Table 11. Comparison between RDM, DAP, and DAPP

Table 11 summarizes the main differences between the three methods in terms of four aspects: the main focus, types of actions, strengths, and weaknesses.

- RDM employs various perspectives of the future to facilitate a thorough study of modeling findings, assisting in the identification of a static plan that is resilient(Walker et al., 2013). In addition, it performs well over a wide range of conceivable futures but may not perform ideally in any single future(Lempert et al., 2003). RDM framework does not include any actions during the implementation of the method. Moreover, RDM has an advantage in terms of developing a set of promising planning alternatives that demonstrate the major trade-offs between the relevant objectives (Kwakkel, Haasnoot, et al., 2016). However, the expense of constructing the necessary system models frequently places RDM studies outside the financial means of many decision-makers. In addition to the needed time to apply the method, it cost a long time for software, especially since the method is iterative (Groves et al., 2019; Kwakkel, Haasnoot, et al., 2016).

- DAP was created expressly to aid in the implementation of long-term planning to handle the uncertainty (Walker et al., 2019). Therefore, it is developed to protect the initial plan by multiple actions that are discussed before. DAP's advantage is the variety of actions that can be taken and that challenges planners to examine changes across time rather than only at one or a few points in time (Marchau, Walker, Bloemen, et al., 2019). On the other hand, there is lacked practical examples of this method in reality, and it depends on the assumption throughout the whole process which makes it more static in dealing with a change in predictions (Marchau, Walker, & van der Pas, 2019).

- DAPP depends on the strategic vision of the future with considering short-term actions to handle deep uncertainty. As mentioned before, the method developed from DAP and adaptation tipping points, which means that it has similar diversity of DAP actions. The adaptation pathways and tipping points concept reinforces the adaptivity of this method, it is dynamic in dealing with different scenarios of the future(Kwakkel, Haasnoot, et al., 2016). However, Simplifying the problem may lead to neglecting the dynamical relationships between the complex interrelations in the system, and thus neglecting the multisectoral problems so that it is difficult to understand the essence of the problem and its ramifications (Kwakkel, Haasnoot, et al., 2016; Shavazipour et al., 2021). Therefore, the preferences between the paths will not be clear because stakeholders in different sectors are unable to identify the risks coming from other sectors.

3.4 The role of hydraulic structures in the water system, objectives, and requirements

Hydraulic structures play an important role in the delta regions, whether these structures perform their function in protecting the delta regions from flooding, supplying fresh water, navigation, and so on. These structures already exist and are exposed to various factors of change, whether naturally related to climate change and sea level rise, or caused by human activity, renewal, and renovation are part of the decision-making process related to the adaptation of the delta. Therefore, the timing of renovation and replacement is essential, an early replacement will lead to disinvestments and late replacement will have risks and loss of societal benefits (van der Vlist et al., 2015). Moreover, Hydraulic structures play different roles for different functions, and when these structures approach the end of their technical or functional life, it becomes necessary to decide on replacement and renewal (Kallen et al., 2013). The water management system is not limited to hydraulic structures such as concrete and steel, but rather extends to the entire system of the water bodies behind and close to the structures, and how functions of these structures influence the water management system and their reflections on the surrounding urban area. These are also social and economic considerations that must be taken into account in the decision-making process regarding the renewal and renovation of infrastructure.

The decision-making process requires a deep and broad understanding of the context in which it is applied, which means understanding the requirements and objectives of the system and the relationships between all elements and the limits of influence, and many inputs that must be present. In the three methods in this research, the common denominator is what is called stage setting, which means creating a knowledge base about the system that forms the basis for decision-making. In other words, it is important to understand the role of infrastructure within the entire system, its functions, vulnerabilities, opportunities, and tipping points, and the requirements of this infrastructure to be adaptive and resilient.

Hydraulic structures vary in the functions that were specially built to provide them, some of these structures are single-function like Bathse Spuikanaal with a sluice, and multi-functional structures like Eastern Scheldt barrier, and these functions differ in the degree of their importance and priority according to society and all stakeholders, and this also affects the process of renovation of the infrastructure and making decisions, in which direction should the solution be and what functions can be dispensed with future?. Functions are defined and determined based on specific objectives, some of these goals remain valid, and others are because of a change in social and political interests in the future.

Functionality is defined as "what a structure should be able to do" to fulfill a set of functions (van der Vlist et al., 2015). This function will affect the technical performance of the structure, which in turn will also adversely affect the functionality, and this point will be studied in more detail in the next sections. Currently, many civil assets are close to the end of their technical and functional life, and this raises the question of systemic development of alternatives to new solutions and new strategies for replacement and renewal (Hertogh et al., 2018).

Concerning the existing infrastructures in the southwest of the Netherlands, protection from floods is the most important objective since the Delta works now, and this is represented by systems linked to each other within the framework of flood risk management, which is known as the CASCO concept. It is an integrated approach to the design of frameworks in the urban landscape (Sijmons, 1991). Many hydraulic structures perform different functions diverse between flood protection, navigation, land connectivity, and environmental diversity as well. However, the dilemma remains in how to gradually move towards a more flexible infrastructure that is more open to future changes while preserving the main objective on which the delta works were implemented, which is flood protection. From this argument, a basic question emerges regarding the renovation and renewal of the infrastructure, whether what is now owned must be preserved? or new opportunities, new goals, and therefore new functions for infrastructures must be seen? hence the need to study the requirements and objectives of the infrastructure.

To define the objectives of existing infrastructure, it is important to understand definitions related to functional, technical, and economic lifespans. Hertogh et al (2018) briefly explain the end of each life span, Technical life span ends due to degradation and a negative impact on functional performance. The economic life span ends when the costs of renovation and renewal become too high and replacement becomes the best solution from a financial point of view. Functional life span ends due to external changes such as intensive use, heavier loading, climate change, and so on.

These three lifespans overlap with each other in some points and differ in others, and open the discussion to the contribution of the so-called life cycle management (LCM), which is a major concept that must be considered in the renewal and renovation program (Hertogh et al., 2018). Life cycle management includes three aspects: life cycle performance, life cycle costs, and life cycle risks.

Life cycle performance can be defined as the degree to which the value of an infrastructure meets the expectations of stakeholders who have different preferences. In this context, the importance of the role of decision-making methods in defining the needs of stakeholders, what are the standards that can express the preferences of these stakeholders, and do municipalities and farmers, for example, have a common interest in the function of this infrastructure? if these preferences are not subject to parameters, how can the process of renovation be directed?

Life cycle costs aim to optimize the value of infrastructure within a specified budget and apply strategies to ensure that costs remain within a reasonable range (Hastings, 2015). There is also an aspect that can be described as a parameter to determine the effectiveness of achieving goals. Should the goal be achieved at any cost?

Life Cycle Risk is about identifying, analyzing, and mitigating risks. This is an important aspect of the decision-making process, especially concerning risk priorities. These three parameters interact with each other during the life cycle of the infrastructure. Replacement decisions and many decisions in construction operations are about trade-offs between these three aspects (Hertogh et al., 2018).

Each of these three aspects poses questions and challenges to decision-making processes. Costs, performance, and risks are all essential terms in the process. They are parameters for the life cycle management of infrastructure and therefore essential in the process of deciding on renovation or replacement.

In addition, there is also the concept of tipping points, which is an essential and pivotal part of the DAPP method, and this concept is closely related to the functional life of the infrastructure. Kwadijk et al (2010) define the tipping point in this context as follows: " point where the magnitude of change due to climate change, or sea-level rise, is such that the current strategy will no longer be able to meet the objectives".

The foregoing shows that objectives are not simple terms that can be defined abstractly in isolation from their context but are closely related to functionality and technical performance, and therefore the question about meeting or not meeting the required objectives is not easy to answer, especially about function indicators and tipping points of hydraulic structures that are dynamically affected by changes, climatic and external influences (van der Vlist et al., 2015). In principle, the objectives of the systems can be defined in broad outlines. The flood asset system, for example, was established to protect the Netherlands from flooding in the first place, and this is a goal in the broad sense of the system, but when we analyze each hydraulic structure separately, we find that there are other functions for this structure and each of them constitutes a functional component within a larger system and therefore objectives overlap. The flood protection system becomes more complex and thus the goals are not clear and independent of performance and function indicators. Thus, each hydraulic structure needs a separate analysis to understand its functions and the impact of the drivers.

3.5 Future states of the delta

In the previous sections, objectives and drivers are discussed, and their role in the decision-making process is an essential part of the context preparation phase. In this research, as mentioned in the first chapter, there is a state of uncertainty about the future states of the delta, and the uncertainty is summed up in the direction of the decision and the political arena. Therefore, it is also important here to define these four states in terms of opportunities and risks and the mechanism of action of hydraulic structures in each state. These future states represent directions for solutions, and they are considered corners for the directions of delta redesign, therefore they are the foundations of the decision-guiding process. Studying adaptation pathways and decision-making without directions for resolution is a very complex process and the uncertainty about it will be multidimensional, such that there is uncertainty about SLR and uncertainty about the future state of the delta.

Protect closed

This future state is a solution direction when the surge barriers close more often than acceptable. In this state, enormous changes will happen in different areas of the delta.

One option is to replace the Maeslantkering with a dam with a lock complex. In that case, the Rhine and Meuse can no longer drain freely via the Nieuwe Waterweg. Similar to the Ijsselmeer, an inland lake will form behind the barrier. This lake will form at the location of the existing waters in the lower river area such as the Lek, Waal, Merwede, Nieuwe Maas, Oude Maas, Hollands Diep, and Haringvliet (total surface area of 400 km2). Consideration could also be given to linking other storage areas to the lake, such as Grevelingen and Oosterschelde, thereby increasing the surface area (total surface area of approximately 1000 km2). There are roughly three alternative paths within this Protect-closed solution direction. Firstly, stick to the current discharge distribution of the Rhine and Maas branches and a pump-discharge system at the Nieuwe Waterweg and/or Haringvliet. Secondly, Adjust the discharge distribution and more discharge via the IJssel and the IJsselmeer in combination with a (smaller) pump discharge system at the Nieuwe Waterweg and/or Haringvliet. Thirdly, Divert the Waal and Maas via the southwestern delta, namely via Grevelingen and/or Haringvliet whether via a pump discharge system at a closed flood defense system or with an open barrier.

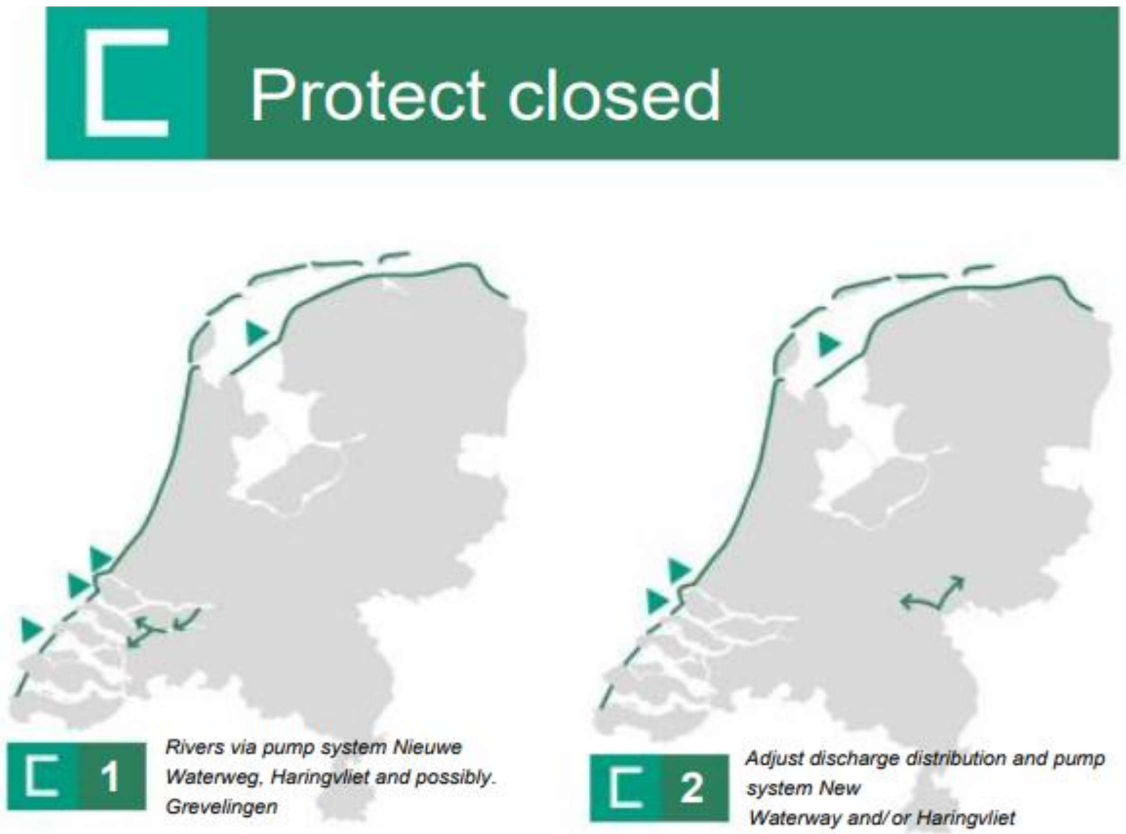


Figure 13. Protect closed state (Deltares, 2022)

To be able to pump out the average discharge from the Rhine and Meuse directly, with the current type of pumps, approximately 1 to 1.5 km linear meter along the coastline is needed for the pumping system, and for the maximum discharge, this is approximately 6 to 10 miles.

Pumping water will cost more energy at greater SLR and greater peak discharges due to climate change. In the Protect-closed solution direction, the OSK may also be closed in the long term and even later itself, and the maintenance and growth of the new coast must come from alternative locations because the islands will largely lie on the site of existing sand extraction. The alternative locations are deeper places, making the extraction more expensive. The coast will change dramatically (Deltares, 2022)

Protect open

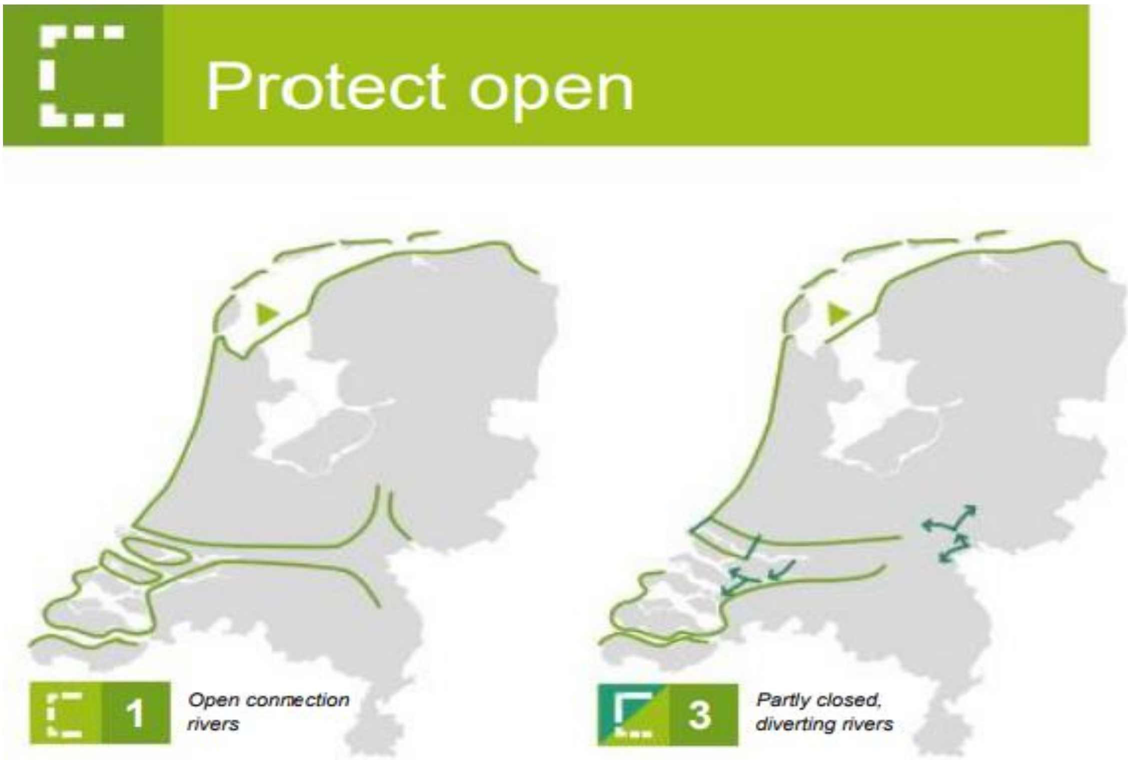


Figure 14. protect open state (Deltares, 2022)

The current strategy of the Netherlands is a combination of open protection (Eems-Dollard, Nieuwe Waterweg, Eastern Scheldt, and Westerschelde) and closed protection (IJsselmeer, Grevelingen, Haringvliet, North Sea Canal). In the solution direction Protect open, the large river branches remain in open connection with the sea with a need to invest in dikes inland. The influence of the tide extends further upstream as the SLR increases, this means that under average conditions the river water levels will increase just as much as the SLR in the lower river area.

Seawards

Figure 15. Seaward's state (Deltares, 2022)

Lack of space on land and developments at sea can be a trigger for the solution direction Seaward. There are two variants:

1) a seaward widening of the coastal strip, which further protects the coast, and 2) islands that shield wave action on the coast and connect with flood defenses. In both cases, this involves radical adjustments to the coastal system that not only provide new space for functions but also the functions in the surrounding areas, such as nature, housing, and tourism. Another idea that fits within this solution direction, but which has mainly been mentioned to promote climate mitigation, is the implementation of a North Sea dam (between Norway and Scotland, and across the Channel) (Groeskamp & Kjellsson, 2020)

Placing islands off the Dutch coast is a more radical alternative. The islands can be made in phases, which with continued SLR can be connected with barriers. Once built, further adaptation of the islands and defenses to further SLR will not be easy. A lot of space can be created with the islands and can be used for various functions. This alternative needs a lot of sand (Deltares, 2022).

Moving along

Due to the environmental considerations and the associated long-term adaptation tasking, and possibilities for combining with other developments, moving along (Meebewegen) can be an attractive strategy. In this solution direction, dikes are not raised.

Instead, a greater probability of flooding is accepted and the solution to reducing the flood risk sought is reducing the adverse effects of a flood. Water thus becomes more guiding for spatial planning.

move along

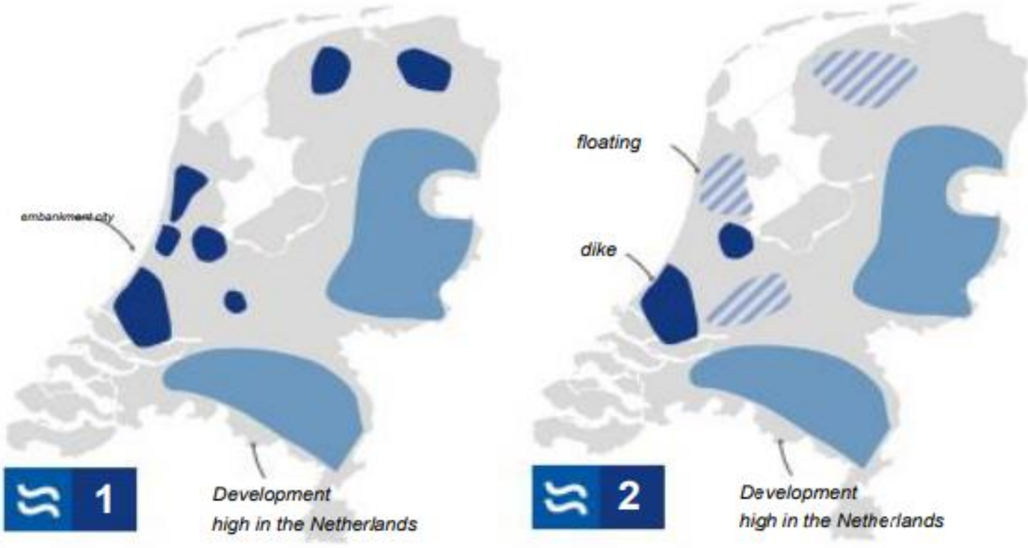


Figure 16. Moving along state (Deltares, 2022)

This solution direction starts with small-scale adaptation by giving limited space to the water and adapting land use (for example with alternating polders), avoiding building in risk areas and stimulating developments in higher parts of the Netherlands and subsequently giving space to water on an increasingly larger scale and increasingly concentrating residential areas in higher parts moving along. The current barriers remain preserved and more and more space is becoming available made to collect abundant rainwater and river water.

In coastal areas with extensive land use and sufficient sediments, such as parts of the Northern Netherlands and the Zeeland delta, is being used on a large scale in experiments with natural land level rise. The floodplains will become building-free zones. The peat areas are being rewetted to prevent soil subsidence and emissions and create space and resilience for nature to adapt to climate change. Building in peat areas is very limited, provided it is temporary and movable, on piles or floating. The use of floating neighborhoods (such as Schoonschip in Amsterdam) is being scaled up as an experiment for floating cities. The possibility of a dyke compartment city (a city surrounded by a high dyke) is being investigated.

When continuing on the path of moving along, a choice arises between 1) a path in which much more migration directions higher areas, in combination with limited floating construction in the low-lying Netherlands, and 2) a path in which many floating cities and mega mounds are created. In the long term, it is difficult for the island cities to be protected behind dike compartments and will have to be relocated, floating, or become mega mounds (Deltares, 2022).

3.6 Eastern Scheldt system

The Eastern Scheldt sea is located in the southwest of the Netherlands, entirely in the province of Zeeland. It forms a central part of the former estuary area of the Rhine, Meuse, and Scheldt. The Eastern Scheldt is bordered by the dikes of the islands of Schouwen-Duiveland, Tholen and Sint Philipsland, Noord-Beveland, and Zuid-Beveland and the dams of the Delta Works. The area is approximately 35,000 ha, surrounded by a 194 km dike, 40 km as the crow flies from east to west, and 27 km from north to south.

Empirically, The Eastern Scheldt system term refers to the Eastern Scheldt as a water body, the barrier, and all surrounding dikes, including the Zierikzee harbor canal and the canal through Zuid-Beveland. In addition, the project area covers that part of the Voordelta (See figure 16).

The Eastern Scheldt is the largest national park in the Netherlands. The landscape is always different because of the tide. At low water, the tidal flats and flats become visible, which then temporarily disappear again at high water. This so-called intertidal area in the delta of the Rhine and Meuse, where is home to an enormous wealth of plants and animals. The Eastern Scheldt is also of great importance for the shellfish sector. It is the most important production area for shellfish in the Netherlands and is also of great value for tourism and recreation (Wittenveen + Bos, 2017)

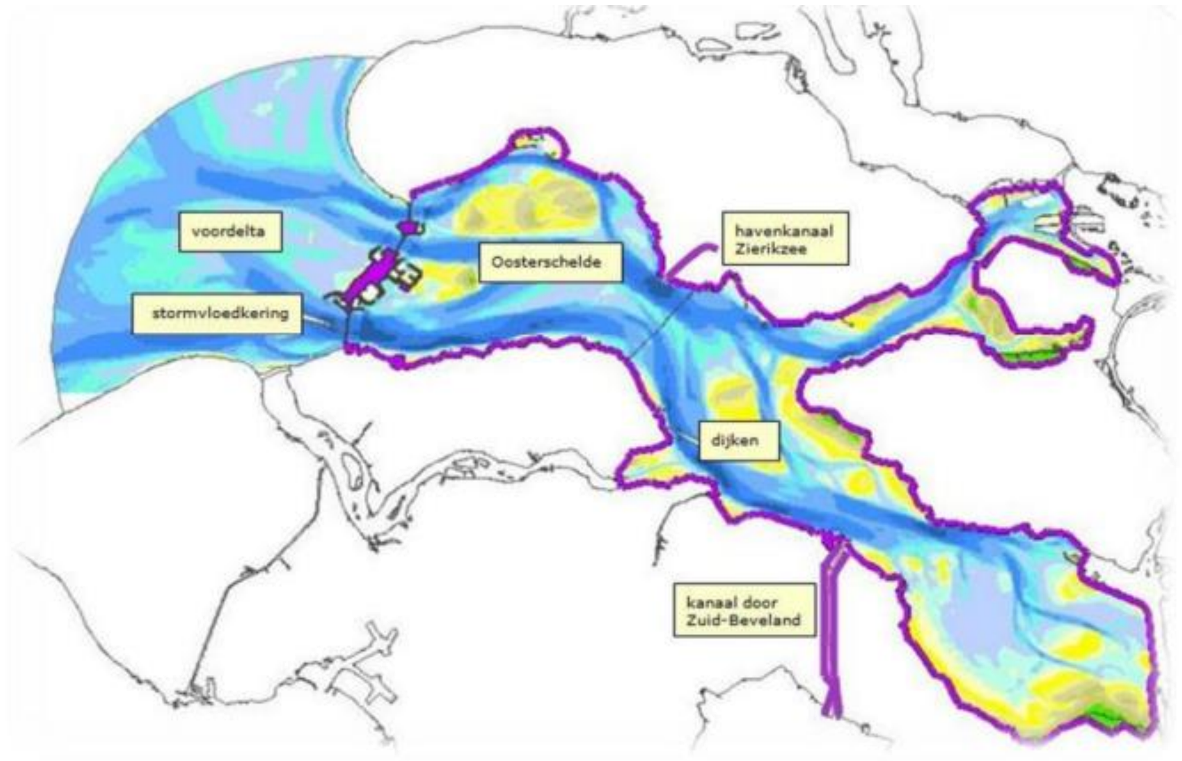


Figure 17. Eastern Scheldt system (Wittenveen + Bos, 2017)

Functions

- Flood protection: it is the main objective of the barrier, which is designed to withstand a flood that occurs with a 1:4000 probability of occurring
- Traffic: It connects Schouwen-Duiveland and Noord-Beveland
- Shipping: There are two main navigation channels in the Eastern Scheldt. One main channel is the Roompot, which runs from the Bergsediepsluis in the Oesterdam towards the North Sea, via the Roompotsluis. This is mainly a route for recreational boating.
  The other main navigation channel is the main transport axis Ghent-Germany.
  45,000 ships cross the two navigation channels with a combined cargo of approximately 25 million tons. In addition, there is a lot of shipping for shellfish fisheries.
- Environment: It is a special nature reserve with many different animals and plants, there is still ebb and flow in the Eastern Scheldt and the water remains salty.
- Fishing: farming Various forms of fishing take place in the Eastern Scheldt sea, namely mussel and oyster farming, trawl fishing, cockle fishing, fishing with fixed gear (including lobster fishing), and weather fishing.
- Recreation: The recreation sector in the Eastern Scheldt has seven types of users: (1) day-trippers and overnight visitors, (2) water sports enthusiasts (pleasure boats), (3) sport fishermen, (4) pier piercers, (5) divers, (6) bird watchers and (7) beach holidaymakers.
- Wind energy: In total there are about 28 wind turbines with a capacity of 80 MW. Many wind farms are located on the Eastern Scheldt.
- Tidal energy: In the context of innovation, Rijkswaterstaat had five tidal turbines installed in the Eastern Scheldt at the end of 2015. This is the largest tidal flow project in the Netherlands. The turbines have a total capacity of 1.2 MW. There is now a permit to also install turbines at a second opening in the Eastern Scheldt (Wittenveen + Bos, 2017)

Drivers

In the first chapter, possible scenarios for SLR were presented, which is a dominant driver that directly affects functional and technical performance. The scenario was classified into three levels: optimistic, middle, and extreme within a time range from 2050 to 2150 (KNMI, 2021).

Optimistic SLR			Middle SLR			Extreme SLR		
0.15 m	0.3 m	1 m	0.25 m	0.6 m	1.2 m	1 m	1.5 m	2 m
2050	2100	2150	2050	2100	2150	2050	2100	2150

Table 12. the three expected scenarios of SLR

The second driver is socio-economic change. In this research, only population growth and its impact on functionality are addressed, and only two figures were adopted: 19 million people in 2050 or 16 million (Wolters et al., 2018). Given that there are other socio-economic developments linked to population growth like land use and commercial activities but because of a lack of information about these developments in the future, the research is limited to population growth. This driver is classified in the second level because it affects and is affected by functionality.

Socio-economic (Population in 2050)	
16 million	19 million

Table 13. the expected increase or decrease in population in 2050

The third driver is deterioration, which directly affects technical performance and is directly affected by the first driver, and this driver depends on the technical components of the structure, which are directly affected by SLR. Here it is important to understand the relationships between drivers, technical components, and functions.

The first driver (SLR) directly affects the technical components and thus the functional performance, and indirectly affects the socio-economic development.

The second driver (socio-economic) affects functionality directly, and the first driver is indirectly affected by functionality.

The third driver (deterioration) affects and is indirectly affected by functionality through the technical components of the structure.

Vulnerabilities, opportunities, and tipping points

After clarifying possible future states of the delta, defining functions and drivers. It is necessary to define the direction of the decision process. What is meant by the direction here is the consistent paths to reach the required objectives, even if the objectives were defined from the beginning, there are several paths and directions to reach. Here, the importance of defining and clarifying the role of the decision-maker emerges. What is their position? What is the ability to change? Permissions are absolute or restricted? Are decisions dependent on the ability of a higher (higher decision-maker)? Do they want to be proactive or defensive?

In the case of this research, decision-makers for the renewal and replacement of infrastructure depend on the decisions of higher levels of government regarding the future states of the delta. Therefore, the nature of the role being played is important, defensive, or proactive. What is meant here by defensive is as follows: following up on the current policy and waiting for the four directions of solution or other directions of solution from the decision-maker, then decisions are taken within the available space. For example, the government decided to close the area in the year 2100. In this case, the role of the decision-maker (renewal program) will be how to direct this closure and make decisions about the infrastructures that must be in line with the government's decision.

Optimistic SLR

As mentioned before, the research focuses on the decision context stage, where the scope is determined, uncertainty is identified, and policy options and their consequences are analyzed. Therefore, the fundamentals of the decision should be robust to move to the modeling phase. However, aspects like definitions of success and translation of stakeholder interests are difficult to meet or include because each stakeholder defines success in a specific context without considering multi-sector interests and the consequences of the actions that can be taken. The literature on DMDU emphasizes the fact that DMDU methods are engines to generate and examine possible futures (Marchau, Walker, Bloemen, et al., 2019). As a result, the iterative process is also important in the context stage to generate and motivate new perspectives of the stakeholders. Although DAPP and DAP methods are easier than RDM in terms of explaining and clarifying the decision-making process for the stakeholders, these two methods have limitations related to trade-offs and assumptions as mentioned before in this chapter. Therefore, playing with the complexity in the context stage is essential to make the decision process understandable and mitigate the conflict of interests between the stakeholders.

Table 14, and subsequent tables, clarify and support the decision-making process. On the left side of the table are the previously described functions as well as the technical elements, and at the top of the table is the first driver, which is an optimistic scenario of SLR with the timeline. The colored blocks represent the current policy and the four future states of the delta. The meaning of each symbol and each color is shown below the table.

The purpose of the following tables is to illustrate how the functions of the Eastern Scheldt system will be between 2050 and 2150 in 5 states under the impact of various drivers starting from sea level rise, socio-economic developments, and deterioration. They refer to where the function no longer achieves its goals. They help where an action is needed and how this action affects the drivers. Also, tables illustrate the interconnection between drivers. As a result, the decision-maker can see more comprehensively the possible ways of solutions and where a decision should be made to renew or replace based on the tipping points.

Estimation of the timing of the tipping points is derived from research conducted by Wittenveen + Bos consulting Engineers BV for Rijkswaterstaat within a project called Integral safety Oosterschelde (Wittenveen + Bos, 2017). The aim of the tables is not to study the tipping points and provide an accurate estimation of the timing, it is an initial tool to scope the scene for different stakeholders.

The tables show the status of each function in five different states: open, closed, moving along, seawards, and keeping on the current policy without making decisions. It is assumed that each state began in the year 2050.

- Keeping on the current policy

In 2050: all functions are still valid and the technical performance as well except the height artwork needs to be maintained. Thus, there is an opportunity to gain more time to re-think about Eastern Scheldt system.

In 2100: all functions are valid. The technical components like stability rubble stone and strength and stability artwork need actions to maintain, the high artwork is remarked as red too because it is assumed that no actions is taken in 2050 because the SLR does not occur in 2050 as expected, then maintenance action for this component postpones to 2100.

In 2150: all functions are still valid, whereas the technical components require renovation or maintenance. There is no information about the validity of the piping element, which means that there is no potential decision about this element at this moment.

Conclusion: keeping on the current policy in the optimistic SLR simplifies the context stage because there are no tipping points for any function. Therefore, all interests of stakeholders are kept as they are currently, with no updates on the definition of success, no constraints, and vulnerabilities. The uncertainty is limited to specific technical components.

- Close state

In 2050: the environment and fishing industry are affected. They will not valid in case of closing because there is no tidal movement to keep on the life of flora and fauna. Therefore, external actions are needed to keep on the environmental life and fish farms. However, a close state will be implemented for the whole flood protection network system which means that solutions in other areas are excluded unless a solution of close-open (current policy) is adopted. For technical components, it is the same situation as the current policy.

In 2100: the case of functions is matched to the case in 2050. For technical components, it is also the same as the case of the current policy in 2100. It is also valid for 2150.

Conclusion: there is no direct interrelation between SLR and close state decisions because the current policy is effectively related to the Eastern Scheldt system. But it is important to illustrate to the stakeholders where the tipping points are in case of a close decision based on considerations outside the Eastern Scheldt system.

- Open state

In 2050: in the case of open, the role of the barrier is neglected, the technical components are not included in the renewal and renovation program, the flood function is not needed, and other functions are still valid like shipping, fishing, and energy activities. There is uncertainty about the agriculture and recreation functions, how the saline water will affect agriculture, and how to develop new methods to help farmers to depend on the saline water for specific crops. Also, the recreational activities in the area are not certain how will continue.

In 2100: it is the same as in 2050.

In 2150: there is a knowledge gap about shipping functions. Currently, there is no information on the safety of navigation in the Eastern Scheldt in case of a 1 m sea level rise.

Conclusion: the open state is also a decision based on external considerations of the system because the current policy is valid in the case of an optimistic SLR. In the open state, there are knowledge gaps in agriculture, recreation, and shipping. Therefore, actions and investments should be implemented for these three functions if there are indicators outside the Eastern Scheldt system that the way of solution will be open in the area.

- Seawards

In 2050: there is a knowledge gap about the technical performance of the barrier because the role of the OSK is not obvious in this solution. If it is still a flood protection barrier, how the mechanism of the defense will be and therefore the role of the technical components is still vague. As a close state, fishing and the environment will be threatened because the tidal movement will be stopped. This situation is valid for 2100 and 2150.

Conclusion: the seaward state is more radical than the other states, and hence the knowledge gap is larger. However, with this state, the effects on functions are the same in 2050, 2100, and 2150, because the OSK will be neutral and unaffected by SLR.

- Moving along

In this state, the Eastern Scheldt system will be out of service, except for shipping and energy activities that can be good investments. This state has enormous socio-economic impacts on the whole country.

Main Conclusions

Based on the considerations of the Eastern Scheldt system in the case of optimistic SLR. Continuing with the current policy has more advantages than the other states, most functions are still valid, and no radical changes are needed. Fewer actions to take and investments in wind and tidal energy from now on will be feasible. Objectives and definitions of success for all stakeholders are identified as they are today. Unless external influences occur.

Functions	Optimistic SLR (per meter)														
	0.15 m					0.3 m					1 m				
	2050					2100					2150				
Flood	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Traffic	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Shipping	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Agriculture	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Tidal Energy	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Wind energy	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Recreation	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Environment	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Fishing	A	c	o	s	M	A	c	o	s	M	A	c	o	s	M
Grass cover erosion crown and inner slope	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
piping	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
macro stability inward	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
stability rubble stone	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
height artwork	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
reliability closure artwork	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
piping artwork	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
strength and stability artwork	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M

Knowledge gab	No function	A	Current policy
		C	Close
Tipping point		O	Open
	Different factors	S	Seawards
Validation		M	Moving along

Table 14. functions of the Eastern Scheldt system in the case of optimistic SLR.

For example, now 2025, there is no government direction to adopt one of the four solutions (future states), and the optimistic scenario is the closest to happening. The decision-maker regarding renewal and replacement may take one of the two ways:

Defensive: It will follow the current policy and keep the structure in its current position without renovation. Measurement will be taken only with the height of the lock, such as replacing the cover or increasing the crown, because it is a tipping point, as shown in the table. The year 2050 will pass and the government's direction in 2100 is still unclear. Then the decision-maker will continue with the current policy and take renewal measures for the technical components of the barrier. If the government's direction becomes clear toward the open state, then renewal is not necessary because there are no tipping points for functions in the case of an open state.

Initiative: The decision-maker will look for the number of red and yellow blocks in each of the five paths. The path that contains the largest number of yellow blocks indicates a high degree of uncertainty and involves risks. The red blocks mean the path that most needs renewal and adoption. Renewal Measures such as diverting waterways, raising dams, and so on. In the case of this optimistic scenario, the current policy is the greenest block, which means contributing to directing the solution to stay on the current policy until 2150.

This method does not mean which path is the best or the most feasible, but rather it shows the most robust and the most uncertain, the most robust does not necessarily mean the most economically feasible, for example, the green blocks A in the year 2150 indicate that all functions will be valid, functionally it is true because the barrier can protect in case of the sea level rise by 1 m, but the number of closures will increase, which means an increase in the rate of deterioration of the gates and the rate of repairs, and therefore it is not feasible from an economic point of view.

<u>Middle SLR</u>

- Keeping on the current policy

In 2050: all functions are still valid, but the technical performance needs to maintain.

In 2100: all functions are valid. The technical components need actions to maintain, the high artwork is remarked as red too because it is assumed that no actions are taken in 2050 because the SLR does not occur in 2050 as expected, then maintenance action for this component postpones to 2100.

In 2150: all functions are still valid except traffic that needs action like installing 2 meters planks through the sides of the barrier to protect traffic from the effects of the high water waves or close the traffic movement in high water times. The technical components require renovation or maintenance. There is no information about the validity of the piping element, which means that there is no potential decision about this element at this moment.

- Close state

In 2050: the environment and fishing industry are affected. They will not valid in case of closing because there is no tidal movement to keep on the life of flora and fauna. Therefore, external actions are needed to keep on the environmental life and fish farms. However, a close state will be implemented for the whole flood protection network system which means that solutions in other areas are excluded unless a solution of close-open (current policy) is adopted. For technical components, it is the same situation as the current policy.

In 2100: the case of functions is matched to the case in 2050, except for the traffic function that needs action like in the current policy state. For technical components, it is also the same as the case of the current policy in 2100. It is also valid for 2150.

- Open state

In 2050: in the case of open, the role of the barrier is neglected, the technical components are not included in the renewal and renovation program, the flood function is not needed, and other functions are still valid like shipping, fishing, and energy activities. There is uncertainty about the agriculture and recreation functions, how the saline water will affect agriculture, and how to develop new methods to help farmers to depend on the saline water for specific crops. Also, the recreational activities in the area are not certain how will continue.

In 2100: it is the same as in 2050.

In 2150: there is a knowledge gap about shipping function, traffic, recreation, and agriculture. Currently, there is no information on the safety of navigation and traffic on and through the OSK barrier in case of a 1.2m sea level rise. That has impacts on the socio-economic developments in the area, so it is important to avoid residential projects around Eastern Scheldt because the socio-economic developments are uncertain

- Seawards

In 2050: there is a knowledge gap about the technical performance of the barrier because the role of the OSK is not obvious in this solution. If it is still a flood protection barrier, how the mechanism of the defense will be and therefore the role of the technical components are still vague. As a close state, fishing and the environment will be threatened because the tidal movement will be stopped. This situation is valid for 2100 and 2150.

- Moving along

In this state, the Eastern Scheldt system will be out of service, except for shipping and energy activities that can be good investments. This state has enormous socio-economic impacts on the whole country.

Functions	Middle SLR (Per meter)														
	0.25 m					0.6 m					1.2 m				
	2050					2100					2150				
Flood	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Traffic	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Shipping	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Agriculture	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Tidal Energy	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Wind energy	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Recreation	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Environment	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Fishing	A	c	o	s	M	A	c	o	s	M	A	c	o	s	M
Grass cover erosion crown and inner slope	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
piping	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
macro stability inward	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
stability rubble stone	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
height artwork	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
reliability closure	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
piping artwork	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
strength and stability	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M

Table 15. the validation of the functions in the case of the middle sea-level rise scenario.

Extreme SLR

- Keeping on the current policy

In 2050: all functions are still valid, whereas the technical performance needs to maintain.

In 2100: Traffic function is not valid because the high water can damage the traffic. Knowledge gap about shipping, recreation, and agriculture. There is no information about how many times the gates will close and what is the frequency. Thus, there is uncertainty about the tidal movement and how will affect these functions. Investments in those three domains should be controlled.

In 2150: the same as in 2100

- Close state

In 2050: the environment and fishing industry are affected. They will not valid in case of closing because there is no tidal movement to keep on the life of flora and fauna. Therefore, external actions are needed to keep on the environmental life and fish farms. However, the close state will be implemented for the whole flood protection network system which means that solutions in other areas are excluded unless a solution of close-open (current policy) is adopted. For technical components, it is the same situation as the current policy.

In 2100: the case of functions is matched to the case in 2050, except for the traffic function because of the high-water effects. For technical components, it is also the same as the case of the current policy in 2100. It is also valid for 2150.

- Open state

In 2050: in the case of open, the role of the barrier is neglected, the technical components are not included in the renewal and renovation program, the flood function is not needed, and other functions like recreation, shipping, traffic, and agriculture have uncertainty over their validity.

In 2100 and 2150 is the same as in 2050.

Conclusion: the open state is also a decision based on external considerations of the system because the current policy is valid in the case of an optimistic SLR. In the open state, there are knowledge gaps in agriculture, recreation, and shipping. Therefore, actions and investments should be implemented for these three functions if there are indicators outside the Eastern Scheldt system that the way of solution will be open in the area.

- Seawards

In 2050: there is a knowledge gap about the technical performance of the barrier because the role of the OSK is not obvious in this solution. If it is still a flood protection barrier, how the mechanism of the defense will be and therefore the role of the technical components are still vague. As a close state, fishing and the environment will be threatened because the tidal movement will be stopped. This situation is valid for 2100 and 2150.

Conclusion: the seaward state is more radical than the other states, and hence the knowledge gap is larger. However, with this state, the effects on functions are the same in 2050, 2100, and 2150, because the OSK will be neutral and unaffected by SLR.

- Moving along

In this state, the Eastern Scheldt system will be out of service, except for shipping and energy activities that can be good investments. This state has enormous socio-economic impacts on the whole country.

Functions	Extreme SLR (Per meter)														
	1 m					1.5 m					2 m				
	2050					2100					2150				
Flood	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Traffic	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Shipping	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Agriculture	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Tidal Energy	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Wind energy	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Recreation	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Environment	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
Fishing	A	c	o	s	M	A	c	o	s	M	A	c	O	S	M
Grass cover erosion crown and inner	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
piping	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
macro stability	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
stability rubble	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
height artwork	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
reliability	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
piping artwork	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M
strength and	A	C	O	S	M	A	C	O	S	M	A	C	O	S	M

Table 16. The validation of the functions in case of extreme sea-level rise scenario.

<u>Socio-economic changes and deterioration</u>

In the previous three tables, the impact of SLR on the functions of the Easter Scheldt system and the technical performance of the barrier are studied. Table 17 illustrates the impacts of socio-economic developments on the functions of Eastern Scheldt. There is no accurate number of inhabitants in Zeeland or around Eastern Scheldt specifically, thus the numbers used here are for the whole country, but it is only to refer to how the increase and decrease in the number of inhabitants will affect.

<u>Decrease in inhabitant's number in 2050</u>

- Keeping on the current policy

The functions of flood protection, traffic, and energy will still be valid because the decrease in inhabitants will not affect them, whereas shipping, agriculture, recreation, environment, and fishing are uncertain. This uncertainty is not because of the knowledge gap but due to the interaction between different factors. For example, the state of the shipping function is difficult to determine, because it is not reasonable to say that if the number of inhabitants decreases, the shipping no longer met what is needed. It can be determined if it is known that the SLR harms this function and the boat owners move to other places.

- Close state

If the system is closed, the freshwater from rivers assists in improving agriculture, whereas the environment and fishing are negatively affected whether the number of inhabitants decreases or increases.

- Open state

Shipping, recreation, environment, and fishing depend on the kind of people who move and on the SLR at the same time, and so on.

The same is for the increase in inhabitants, the characteristics of the change are not known if it is because of the SLR or different reasons that are related to the normal demographic process.

In terms of deterioration and its impacts on functions, the deterioration affects the function negatively but that depends on the SLR that can speed up deterioration, and also the socio-economic developments. For example, more use of the surface of the barrier for traffic will speed up the deterioration and reach the road to the end of life, so the relation between functions and deterioration is two-direction.

Functions	Socio-economic (Population in millions)										Deterioration														
	16 m					19 m					2050					2100					2150				
	2050					2050																			
Flood	A	c	o	s	M	A	c	o	s	M															
Traffic	A	c	o	s	M	A	C	o	s	M															
Shipping	A	c	o	s	M	A	C	o	s	M															
Agriculture	A	c	o	s	M	A	c	O	S	M															
Tidal Energy	A	c	o	s	M	A	c	O	S	M															
Wind energy	A	c	o	s	M	A	c	O	s	M															
Recreation	A	C	o	s	M	A	c	O	s	M															
Environment	A	C	o	S	M	A	c	O	s	M															
Fishing	A	C	o	S	M	A	c	o	s	M															
Grass cover erosion crown and inner slope	A	c	o	s	M	A	c	O	s	M	A	c	o	s	M	A	c	o	s	M	A	c	o	s	M
piping	A	c	o	s	M	A	c	O	s	M	A	c	o	s	M	A	c	o	s	M	A	c	o	s	M
macro stability	A	c	o	s	M	A	c	O	s	M	A	c	o	s	M	A	c	o	s	M	A	c	o	s	M
stability rubble	A	c	o	s	M	A	c	O	s	M	A	c	o	s	M	A	c	o	s	M	A	c	o	s	M
height artwork	A	c	o	s	M	A	c	O	s	M	A	c	o	s	M	A	c	o	s	M	A	c	o	s	M
reliability closure	A	c	o	s	M	A	c	O	s	M	A	c	o	s	M	A	c	o	s	M	A	c	o	s	M
piping artwork	A	c	o	s	M	A	c	O	s	M	A	c	o	s	M	A	c	o	s	M	A	c	o	s	M
strength and	A	c	o	s	M	A	c	O	s	M	A	c	o	s	M	A	c	o	s	M	A	c	o	s	M

Table 17. Impacts of socio-economic developments and deterioration on the function of the Eastern Scheldt system.

3.7 Interviews

The questions of interviews centered on 7 main points: priorities of the functions, Eastern Scheldt in the four directions of the solution, challenges for long-term planning, tipping points concept, opportunities, zooming in, and understanding the drivers.

Priority of functions

The priority of functions point is about the order of priorities and how to integrate that into the decision-making process. Also, the changes that can occur for the order in the future.

Flood protection is the highest priority, it is not expected to change or ignore this priority in the future. However, all interviewees emphasized that the order of priorities is a political discussion. As one of the interviewees remarked:

‘’ That is politics in general, but the main function is safety, how to protect your country from flooding and disaster in future.’’

For other priorities, Environmental trends may play a role in changing priorities in the distant future. The discussion about ecology is open and requirements can change with time, which is dependent on international policies and European decisions. One of the interviewees remarked remarked:

‘’Flood protection is the main objective. Ecology is also important, and its considerations can play a role in opening the discussion for adjustment on priorities.''

Eastern Scheldt

This finding focuses on how the situation of Eastern Scheldt as a system will change, the importance of the barrier, and the societal challenges.

Most answers about the situation of Eastern Scheldt as a barrier or as a system will remain as the current situation. Therefore, the current policy is expected to continue in the future. However, some changes in functions like transport and navigation can happen because there is uncertainty about the height of water and how the waves will affect these functions, but that is not a complicated issue because the importance of transport and navigation functions is not high for the Eastern Scheldt system.

OSK is the main structure in the southwest delta and because it is designed to protect against flood even in extreme conditions, it is not a high priority to change as one of the interviewees said:

'' It is good to think or start from a zero scenario, and then check what will happen, and how the failure mechanism can be generated. It is essential to look at the area around, the ecosystem's conditions, and the priorities. Many aspects need to be checked in the delta. But in all cases, I think that Eastern Scheldt is not one of the highest priorities in the delta region now.''

Not one of the highest priorities means there is no need to make radical decisions or take emergency actions. Moreover, the dikes around the Eastern Scheldt area could be considered more important than the barrier itself as one of the interviewees said:

‘’ I think the dikes are more important than the storm surge barriers for the safety aspects if we remove the dikes then everything will float within a day and then we remove the storm surge barriers. ‘’

This statement points to more room in the system to create adaptivity by thinking of other solutions in other structures. Therefore, Eastern Scheldt is more flexible in case of change in the flood protection system.

Challenges for long-term planning

The questions were centered around the social and political challenges, and the influence on the decision-making process, in addition to the challenges to formulate the objectives and constraints of the system.

For this finding, there are a lot of perspectives regarding the challenges, the main challenges that can be mentioned are Different mentalities between different generations, incorporating the uncertainty over socio-economic developments, the governments usually looking to achieve short-term goals, and integrating the knowledge of different disciplines and different datasets.

Experts in water infrastructure remarked on the last point and emphasize the importance of using uniform databases:

'' one person is working on navigation another person is working with ecology and they should use the same data sets, they should all work together towards the same objective of that phase, and that's difficult to organize''

The principle of tipping points

Tipping points are part of the DAPP method and also an important concept in the decision-making process in general because it is a trigger to change the direction of solutions, the interviews discussed the conditions and timing factors.

There is consensus on the importance of the concept of the tipping point but the knowledge that specialists have played a role in understanding this concept. One of the interviewees who has a background in economy remarked that determining tipping points is difficult from an economic perspective because they depend on complicated criteria, whereas other experts from technical backgrounds find the tipping points a good concept to create adaptivity. After all, the concept depends on the technical norms that you apply in the system. one of the interviewees emphasized this point:

'' adaptation tipping points depend on the climate system itself; you have physical tipping points and economic tipping points. In the adaptation tipping point, you have all types of aspects and sometimes it relatively depends on the stakeholder but also safety. that depends on the norms that you apply''

The opportunities

The opportunities that can be adopted in the decision-making, how to seize the opportunities by making investments that can be robust in all directions of solutions. For the OSK, there is no room to adapt for an expert in hydraulic infrastructure but looking at Eastern Scheldt as a system there is an opportunity to merge some functions by re-evaluating and re-think the design details and also investing in agriculture.

Zooming in

Zooming in point is discussed to check the argument of starting with the whole system or studying each structure separately. It is important to integrate the analysis of the system as a whole and as partial components, because ignoring some specific details in some specific components causes failure. One of the interviewees remarked:"

'' you have to look at your whole system and also at the technical components. For example, if you only look at the safety aspect of the storm surge barrier, you have to understand the system better and focus more on partial failures.''

Understanding the drivers

It focuses on the relationship between the drivers and how each driver affects and is affected by other drivers and functions as well. The relation between drivers is complicated and any change in function results in a driver change. Therefore, it is important to look at all changes at the same time, especially the social economic change because it is difficult to expect and visualize. According to one of the interviewees:

'' In socio-economic terms, if you think about the economic developments that we are looking into now like large population growth, and large growth of GDP. These pressures might be as important as maybe even more important than the other drivers.''

Quotations regarding the seven findings are summarized in table 18.

Sl. No	Quotations	Findings
1	Flood protection is the priority in the past and present, and there will be no change in the order of this priority in the future	Priorities of functions
2	The order of priorities is a purely political discussion, but it can be integrated into the context stage	
3	The order of priorities is expected to remain the same for the foreseeable future	
4	Environmental trends may play a role in changing priorities in the distant future	
5	It is a challenge on a social level, removing it means giving up, it is Icon for the Netherlands, and this point should be a basic point in the context stage	Eastern Scheldt in the future states of delta
6	The function of transportation and navigation is not important for this barrier	
7	The effect of high waves on the functions of the barrier is still under study	
8	The dikes are more important for safety than the surge barriers	
9	Thinking ahead two generations is complicated for long-term planning on a professional basis	Challenges for long-term planning
10	The multitude of uncertainties makes the interaction, in the beginning, difficult	
11	Long-term planning is not possible without understanding the surrounding environment and understanding the behavior of society in it, and this is ignored in the technical evaluation	
12	Different mentalities between different generations	

13	Democracy and the desire of governments to avoid making long-term decisions	
14	The context stage is not independent of other contexts that cannot be controlled	
15	The principle of tipping points is difficult to understand, for example, depreciation occurs gradually and not at a specific point in time	Tipping points concept
16	Timing of tipping points is only a way of understanding the system and cannot be applied in practice	
17	The conditions for the occurrence of the tipping points are good indicators to adapt the system	
18	The only opportunities that can be created are merging functions of the structures	Opportunities
19	Opportunities should be sought in the field of sustainability and agriculture	
20	Some structures cannot find opportunities, such as the Eastern Scheldt barrier	
21	Considerations for the system as a whole may be different from considerations for the structure alone	Zooming in
22	Taking action on the entire network may ignore the specifics of a single structure and thus reflect on the network	
23	The socioeconomic driver is more important than the driver related to sea level rise	Understanding drivers
24	Taking action in response to a particular driver will cause a change in another driver, so the picture should be kept as broad as possible	

Table 18. Quotations and findings of the semi-structured interviews

4 Discussion

Sub-chapter 4.1 discusses the answer to sub-question 1 regarding the comparison between RDM, DAP, and DAPP based on four criteria, and employs the comparison to improve the context stage. The sub-chapter 4.2 discusses a new vision of the relationship between the socio-economic drivers and objectives, and how the functional and technical performance is influenced by the different drivers. A framework to enhance the context stage of the examined DMDU methods is presented in the sub-chapter 4.3. In sub-chapter 4.4, the application of the framework on the Eastern Scheldt case is presented.

4.1 DMDU

In the previous chapter, a comparison between three DMDU methods is made. Weaknesses and strengths of the methods are discussed related to the context stage, and how each method addresses uncertainty in this stage. However, many papers discussed these three methods from different perspectives, but the literature is fragmented (Walker et al., 2013). Therefore, some limitations that can exist in the developed phases of the methods result from a disagreement between different parties on the system, and its relative importance (Kwakkel et al., 2016).

In some literature, the context stage can be described as part of problem formulation, where all aspects are defined. That is wrong because the solutions and problem formulation are interconnected with each other in uncertainty cases. '' Depending on how a problem is framed, alternative solutions come to the fore'' (Kwakkel et al., 2016). Based on that, investigating various aspects of the three DMDU methods is important to look at the context stage from new perspectives. In this chapter, a comparison between RDM, DAP, and DAPP is made based on four requirements: political uncertainty, social uncertainty, assumptions, and tipping points.

Political uncertainty is a key factor in the context stage because it is part of the system's characteristics, influences the objectives, and plays a role as a constraint in some situations. Especially if the government is the decision maker, where the agenda of the parties in charge are different. Discussion over actions and plans in 2100 or 2050 is difficult without considering the political conditions. Therefore, the DMDU method has to consider the political dimensions in its plan. Furthermore, willingness to invest in the renewal and renovation of infrastructure needs suitable political circumstances and political stability to set long-term planning and that is consistent with Haasnoot et al (2013) who developed the DAPP method and include the political uncertainty in the process, both DAP and DAPP create space for a debate between the stakeholders in different phases of the process, in addition, that DAPP also looks at the political benefit at the end of the model. Whereas RDM starts with specific definitions of success and focuses on where a plan fails without looking at the reasons behind it and if there is an opportunity to political maneuver or if the political conditions can be changed. As a result, DAP and DAPP are more sensitive to political uncertainty because various categories are present in the formulation of the context stage.

Social uncertainty is related to the societal agreement on objectives and achieves interests of large categories of society. Contexts that describe dynamic views of people of the value of water management should be part of the context stage (Offermans et al., 2011). RDM concerns the technical robustness nevertheless this robustness is social or not, and because it is more generalist, it neglects the relations between socio-economic drivers and other drivers. Therefore, it is less sensitive to the change in social values that can play role in the decision-making process. DAPP concerns the social acceptance of costs and considers the social values in the process. Furthermore, it emphasizes social robust pathways and looks at short-term actions that have agreement from all perspectives. DAP does not consider social acceptance inclusively in the context stage, but it depends on it as a trigger in the developed phase, it considers a tool to assess the actions and protect the plan.

For assumptions, although DAP considers political and social uncertainty, it designs strategy responses in a pre-specified way to pre-specified situations because it assumes the risks in advance and categorizes the actions based on the risks type, and that is a reason to develop this method and combine it with adaptation pathways. DAPP depends on assumptions as all methods, but it deals with these assumptions in dynamic ways to avoid lock-ins in the pathways. Moreover, it is not only based on the timing of tipping points but the conditions are also considered which gives more flexibility in dealing with assumptions because it creates different chances of possibilities and that adds to what Marchau et al (2019) concluded that DAPP specifies the conditions under which adaptation of the initial plan is continued in the future. In the literature, several studies referred that RDM as a static method in terms of generating solutions, and it concerns robustness. However, the RDM is open to adopting thousands of assumptions and testing thousands of scenarios. It depends on assumptions but the number that can be assumed makes the horizon of the solution too broad. Although that is less sensitive to political and social factors that could occur in developed phases, it starts from a huge number of assumptions.

DAPP depends strongly on tipping points, which make it more dynamic in terms of changing the pathways. The tipping points concept is a trigger to adjust the plan based on the current conditions. DAP has not this concept which makes it less flexible in changing the paths, although DAP depends on corrective actions, it is vulnerable to fast failure in emergencies and a high rate of change in some events like floods and storms. RDM is an iterative method and emphasizes the robust solutions from point A to B, but it does not have the chance to change the line in the middle of the process as DAPP does.

Based on the discussion, DAPP is considered a good option to formulate the context stage because it meets all requirements to set an adaptive plan, which means that its context stage is practical but as mentioned in chapter 3, simplifying the interconnection between the system elements and drivers could lead to misunderstanding of the consequences of actions. Thus, it is important to integrate new improvements into the context stage of DAPP. Table 19 summarizes the results of this discussion.

	Political uncertainty	Social uncertainty	Assumptions	Tipping points
RDM	Less sensitive	Less sensitive	Flexible	-
DAP	Sensitive	Sensitive	Less flexible	-
DAPP	Sensitive	Sensitive	Flexible	Timing/ conditions

Table 19. Comparison between RDM, DAPP, and DAP based on 4 criteria

4.2 Drivers

To evaluate the function of the infrastructure and verify the critical points for each function, it is necessary to study the external drivers that directly and indirectly affect the technical and functional performance of the infrastructure. These drivers are also important elements in the study of the context stage associated with the decision-making process because they determine the direction of the system and the rate at which the tipping point is approached and as the analysis of the Eastern Scheldt system shows, there are complicated interconnections between drivers.

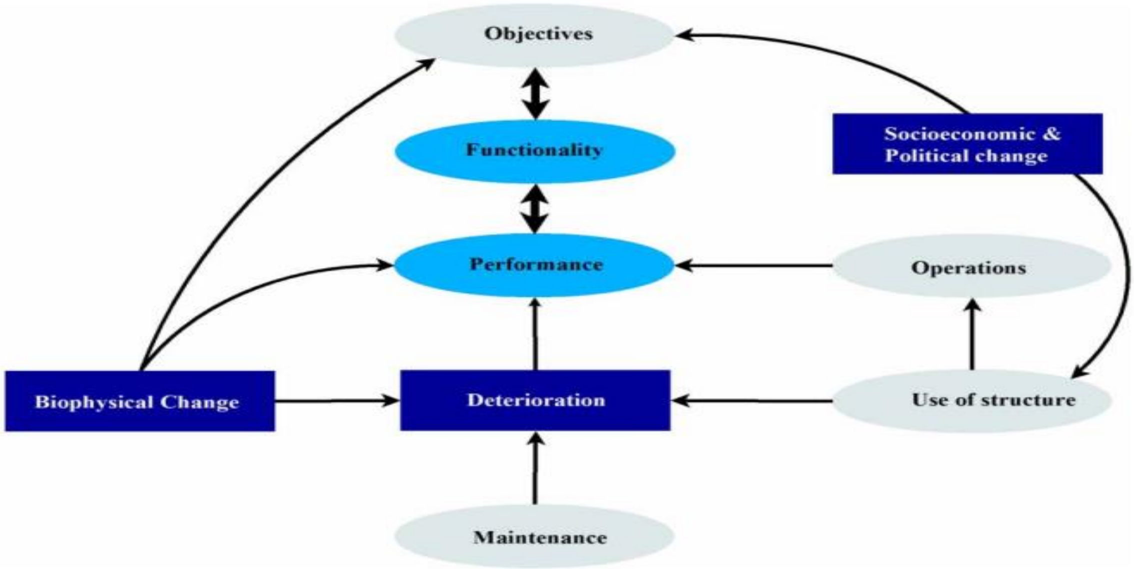


Figure 18. Overview of functionality and performance of a structure related to the key ingredients of a hydraulic structure (van der Vlist et al., 2015)

Van der Vlist et al (2015) identified three different external drivers affecting the functional and technical performance of hydraulic structures: deterioration, biophysical change, and socio-economic change.

These drivers interact with each other in complex and overlapping relationships that make it difficult to separate them. The deterioration gradually and directly affects the technical performance, and thus the functionality, which in turn may affect the objective of the structure, in turn, the change in the objective may be reflected in the functional and technical performance irreversibly, and thus the rate of deterioration that is resulted from a change in operating conditions. Figure 17 shows the relationships and influences between drivers on the one hand and functional and performance on the other hand.

- The deterioration is a driver that affects the technical performance. The structure consists of different technical components, and each component has its characters and materials. Therefore, each component is affected by different rates of deterioration and has a tipping point.
- Biophysical change is a driver that affects functionality and the rate of deterioration. SLR and precipitation patterns are examples of this driver.
- The socio-economic change affects the functionality via altered objectives in the political arena (van der Vlist et al., 2015). Population change is an example of this driver.

Concerning the scope of the research, the relationship drawn by van der Vlist et al (2015) between drivers may be incomplete or lack further links. According to van der Vlist et al (2015), there is no direct or indirect link between biophysical drivers and socio-economic change. In the next sections, it will be shown that there is a relationship between these two drivers. The biophysical change affects the functionality of the structure, which in turn causes socio-economic change. For example, due to SLR, which is a biophysical change, a decision may be taken to close the Eastern Scheldt barrier, which has consequences for fishing and agriculture, and that will lead to the migration of workers in these areas to other places, which means a socio-economic change that will affect other functions such as traffic in the area. However, the function needs to be valid anymore, but it becomes unessential. As a result, a new relationship can be added to figure x between functionality and socio-economic change. (See figure 18)

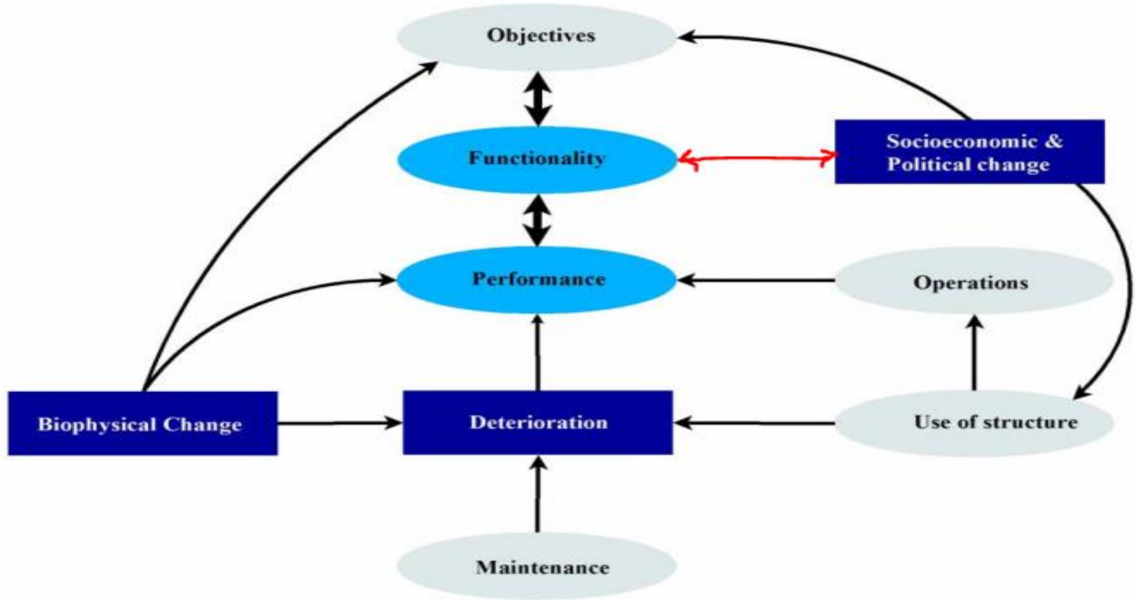


Figure 19. The new addition to the overview (Relation between functionality and Socio-economic change

The point of this new vision of the relationship between drivers is the need to understand the impact of external factors on the system, and how each driver affects functionality and other drivers.

In the context stage, it is necessary to accurately identify the drivers, understand the interconnecting of relationships, and the need to classify these drivers. Biophysical change is the dominant driver, meaning that its source cannot be controlled, although there are measures at the international level to reduce carbon emissions and limit climate change, they are outside the context of research, and therefore this driver can be considered the driver that creates events and causes. The second driver is socio-economic change, a change that directly affects goals and thus functionality, but is indirectly affected by the biophysical change. The third driver is deterioration, which is directly affected by the biophysical change and its effects can be mitigated through maintenance and repair and do not directly affect the goals.

As a result, drivers can be categorized into three levels:

The first level is the dominant driver, which affects other drivers, functionality, and goals, and cannot be influenced.

The second level is the driver who influences goals and functionality and is influenced by the dominant driver.

The third level is the driver who only affects functionality and is affected by other drivers.

The biophysical change could cause a shock to the system. for example, a hurricane, because the implemented strategies cannot handle these events due to the high level of uncertainty over this risk. Therefore, it dramatically influences the objective and makes it difficult to decide to protect infrastructure functions and that is consistent with the result of Hellegate (2009)

4.3 Framework

All the DMDU methods have a context stage but there are some differences. RDM's context stage includes defining uncertainty, relationships between the system components, and objectives, and based on this information, it generates strategies in many futures. As discussed before, RDM is less sensitive to social and political uncertainty. Therefore, a framework to improve the context stage can be added to the RDM. DAP's context stage includes defining success, options set, objectives, and constraints. The context stage of DAP is contained in DAPP's context stage with added improvements focusing on uncertainties and disagreements, and timing of tipping points within different scenarios. The following framework suggests improvements to remove the limitations of these methods to develop long-term plans for adaptive infrastructure.

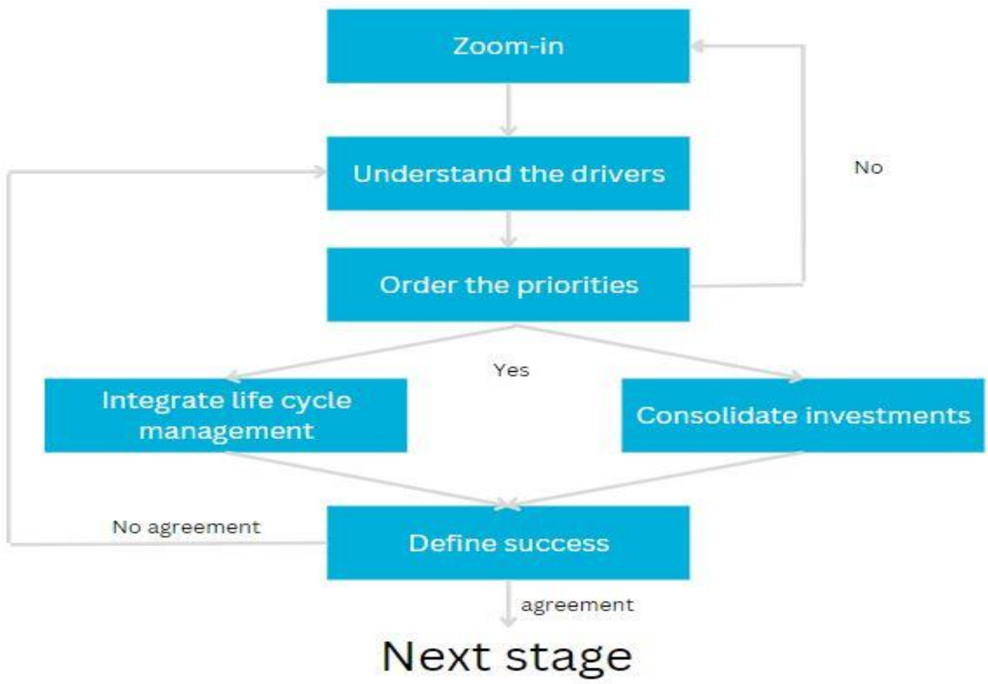


Figure 20. Framework to improve the context stage.

The components of the framework to improve the context stage are as numbered:

- Zoom-in

The three methods emphasize understanding the behavior of the whole system (Haasnoot et al., 2013; Lempert et al., 2003), whether this system is a flooded protection structures network or other water management assets. The context stage attempts to determine the geographical boundaries of the system and the technical details that influence the technical performance of the system. That is an essential point in the decision process, but it looks at the system from above. Thus, it is more effective to add a new step, which is zoom-in the components of the system. The flood protection network in the southwest delta consists of several structures, zooming-in each structure helps in considering the requirements and identifying the vulnerability and opportunity of the structure accurately, and profound knowledge about the technical and functional performance of the structure is created. Also, the state of the structure in various states can be determined, which reinforces the social and political dimensions of actions by concerning all interests of stakeholders without excluding the less powerful and interested parties in the game. Therefore, the infrastructure is integrated into its physical and social context in combinations of opportunities and effective landscaping (Hertogh et al., 2016), and that helps to avoid driving the negative side effects to other areas outside the system.

- Understand the drivers

Many drivers affect the water management system generally. Understanding these drivers is important to determine the moment of replacement and renovation of infrastructure (Kwadijk, et al., 2010). The drivers differ in dependence degree, driver as the sea level rise is difficult to restrain its sources, while other drivers are less complicated. In this research, drivers are categorized into three levels: 1st level affects, 2nd level affects and be affected, and 3rd level be affected and affects but indirectly. Such classifications help the context stage by recognizing the consequences of some actions and plans. It is a balance game, any change in one driver or function affects others. Also, the response of the driver and the speed rate of this response should be considered. However, data about driver's responses are missed, to make renewal and renovations for infrastructure, information about socio-economic drivers must be available. All data sources that are available now do not provide obvious expectations about the socio-economic developments in terms of the solution directions of the delta. Furthermore, the system's response differs based on the drivers, some drivers like biophysical change causes dramatic or non-linear effects on the system (van Ginkel, 2022). Thus, the context stage is better to include a classification of drivers and how connect and interact with each other and with the technical and functional performance. Also, the socio-economic effect on the main objective of the system should not be neglected because the magnitude of a socio-economic driver can be larger than the climatic one.

- Determine priorities

Determining priorities is policy, the government is only empowered to decide on giving up function or keeping it up. However, in democratic countries socio-economic developments and environmental trends can play a role in political decisions and open discussions for new values. integrating the step of determining priorities into the context stage could lead to more reactiveness to the political and social issues and integrate the technical aspects within political and social aspects. This reactiveness does not make more uncertainty, but it creates robustness for infrastructure and opportunity to be integrated into stable political developments. Also, determining priorities step aids to approach different political views and remove boundaries. Decision-making regarding the infrastructure of the delta is a game of trade-offs between the functions, determine priorities can help to understand the interests of all parties and what they are willing to do.

- Consolidate investments

The large uncertainty in coastal regions increases the challenge for investments, especially in low-lying densely populated zones in the Netherlands (van Alphen et al., 2022). In changing conditions, it is essential to look for robust investments that can continue in most scenarios. RDM's context stage includes an opportunity but in technical form, not as investments generate benefits. DAPP and DAP are more flexible to include investments as opportunities in their context stage or at least as actions in developed phases, but they disregard the robustness of investments as a basis in the decision context stage. Moreover, long-term planning is more effective if includes investments as opportunities not only investments for the technical components as Sayers et al (2021) stated. it is safer to isolate the success chances of Investments from the uncertainty over the structure's function to achieve robust investments.

- Integrate LCM

The previous steps of the framework are more generalist and concern political and social contexts. Integrate LCM is more technical and focuses on the structure more than the system. Integrating LCM in the context stage of DMDU methods is an opportunity to understand the functional and technical performance of structures. As mentioned in the previous chapter, Hertogh et al (2018) outlined the three aspects of LCP, LCC, and LCR. LCP contributes in the context stage in defining specific performance requirements and assists to determine the tipping points of performance depending on indicators. LCC is an economic factor that can support the methods to create obvious trade-offs between the different solutions. Especially in deriving the tipping points for DAPP, where can be used the indicator developed by Rijkswaterstaat '' economical end of life indicator' (EELI) (Bakker et al., 2016). This indicator aids the method to make dynamic tipping points, that can be revised every couple of years and before renovating or renewing parts of the structure. LCR in the context stage can reinforce the agreement between the stakeholders about risks, and what the indicators are for acceptable risks.

- Define the success

The definition of success is an essential factor to continue with the decision-making process, so it is important to achieve agreement between all stakeholders before continuing with the next stage. RDM's context stage does not state the definition of success, but it starts from successful outcomes. However, successful outcomes are broad terms, and not all stakeholders need to participate in identifying successful outcomes. The context stage of DAP and DAPP includes a definition of success and what are the necessary conditions for success but they deal with that as input to a conversation between stakeholders (Kwakkel et al., 2016), which is necessary and important but it is not enough. Success should be addressed operationally and strategically too, if the structure operates usefully, it does not mean that it works well strategically. There should be metrics used for translating strategy to operational effects that are equivalent to Vonk et al (2020). For example, if the structure is operated successfully based on specific metrics, the strategic level does not need to be successful because it gives the impression that the system works well and no actions on other parts are needed.

Toolkit for practitioners

The preceding six steps are suggested within a framework to support decision-making regarding adaptive infrastructure and avoid disinvestments in the future. In this paragraph, the steps are presented narratively.

- Separate the infrastructure network into structures and analyze each one's goals, functions, and requirements to identify weaknesses and opportunities.
- Study external influences, and how they interact with one another and affect the functions. This step broadens the perspective to consider disinvestment more carefully.
- After specifying the functions, and vulnerabilities of the system, and understanding the role of the external factors, the importance of each function can be determined based on technical, political, and social considerations in the future to create adaptivity.
- Looking for non-risky investments, this step is crucial to prevent disinvestments that may occur in various conditions by seeking reliable investments that may be realized.
- When the objectives and the functions to achieve these objectives are agreed on, it is advisable to return to the system and assess the situation more technically.
- Based on the proposal investments, and technical, and functional performance indicators, the interested parties can discuss the success definitions from different perspectives to adaptivity that reduces the negative impacts of uncertainty.

4.4 Application of the framework on Eastern Scheldt

To clarify the framework and put it in the practical context, it is applied to the case study step by step based on the Toolkit. This application contributes to a better understanding of the framework as the order of steps and the correlations between them.

1. Zoom in each structure of the system	OSK is less vulnerable to SLR than other barriers in the Netherlands, it was designed for 5.2m NAP (Rijkswaterstaat, 2007). Isolate the Eastern Scheldt barrier from changing conditions aids to concentrate on other functions of the Eastern Scheldt system like shipping, traffic, and fishing. In this case, changes in the OSK are excluded in the potential scenarios that can be generated by RDM or adaptation pathways of DAPP. For opportunities, Eastern Scheldt sea can be considered as an opportunity for solutions outside the system or it is an opportunity in itself. Opportunity for other solutions like using it as water storage for river water or for Volkerak-Zoommeer that can drain in it, and the second opportunity is by giving space for energy farms within the long-term plan to make Eastern Scheldt sea an important source of energy. These plans can be part of the government's agenda. As a result, the Eastern Scheldt system can be integrated into social and political contexts.
2. Understand drivers	After zooming-in the Eastern Scheldt system, understanding the drivers enable profound knowledge of the system. The research studies three drivers, SLR, growth of inhabitants, and deterioration. The analysis demonstrates that SLR affects the functions directly and indirectly, the barrier is resilient until 2150, and potential tipping points are more likely to arise as a result of external policy decisions, which can be considered as policy or socio-economic drivers. Therefore, decisions about Eastern Scheldt are directed by socio-economic developments, and here is an indicator to go further with broad categories of stakeholders and meet their interests. Building residential areas and developing land use is socio-economic development around Eastern Scheldt, then what is the response of the system? More investments in the energy sector will be feasible. Rather than looking for solutions to generate green energy for 100,000 people living in different areas in the Netherlands, it might be a wise solution to generate their energy by Eastern Scheldt if they live near it.
3. Order priorities of functions	Flood protection is the priority in the past and present, and probably there will be no change in the order of this priority in the future. This statement was agreed upon by all interviewees. Shortly, this statement is true, but also this priority is depending on socio-economic developments in the future. For Eastern Scheldt, The priority of flood protection will vary as a result of changes in the socio-economic conditions, such as the relocation of farmers and fishermen to other regions since they belong to a new generation with different perspectives and do not wish to make investments in the area. After completing this stage, it is crucial to go back to zooming-in and comprehend the drivers because they are crucial elements in establishing priorities.
4. Consolidate investments	The future state of the Eastern Scheldt system is reliant on socioe-conomic changes, as was previously stated, and information about it is not now available. Therefore, investments in housing and recreation projects are not robust because the options are open in terms of the four solution directions, but what it is concluded from the analysis of the Eastern Scheldt system is

	that investments in wind energy are robust and applicable in all solutions, close, open, moving along, seawards, and the current policy. Therefore, this investment can be determined from the context stage and isolated from the adaptation pathways or the potential scenarios.
5. Integrate life cycle management concepts	Due to the Eastern Scheldt Barrier's current state, there is no option to integrate various functions or add value to the structure because it already exists. However, based on the determined priority step, performance requirements as a surge barrier are updated continuously. In the analysis of the Eastern Scheldt system, there is no clear indicator of whether renovating or renewing parts of the barrier is feasible economically or not because it does not concern the cost-benefit point. Furthermore, the methods may become static if precise numbers are given at the context stage. Therefore, adopting the EERI indication frees up the decision-making process. This indicator may be used to assess if it is financially possible to carry out renovations every five years.
6. Define success	Since they are already included in the DAP and DAPP techniques, the technical, political, and social criteria for success are not covered in this study. It is evident from the analysis of the Eastern Scheldt that the barrier's flood protection function is effective provided its technical components are in excellent condition, but the frequency of closing the doors in the event of high water is required more information. Operationally, the barrier achieves its function, but this success creates the impression that there is an opportunity for developing the urban area behind, like housing projects, etc. But on the strategic level, a high rate of closing the doors will affect the fishing and shipping movements in the Eastern Scheldt sea. So, raising the dikes with keeping on the barrier open at a reasonable rate is a better solution. In this case, there should be space to make investments on these dikes, so housing projects could be considered regretful actions.

Table 20. Reflection of the framework on the case study.

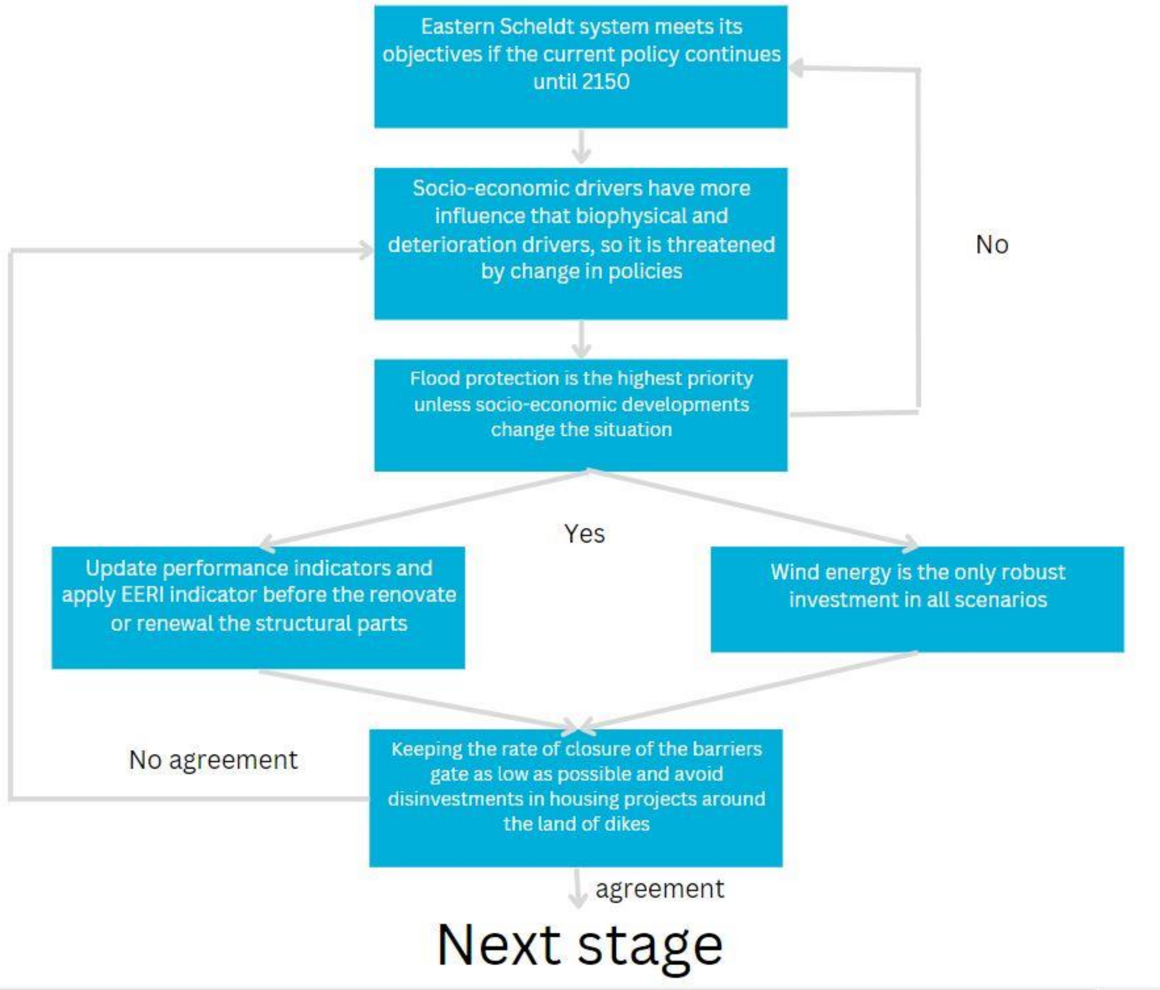


Figure 21. Reflection of the framework on the case study.

5 Conclusions

This chapter includes the main conclusions of the main research question and the three sub-questions based on the findings and discussions in the last two chapters. In addition, the limitations of the study and recommendations for further research are presented.

Based on the main research question:

How to improve the decision-making context stage to deal with deep uncertainty in redesigning delta infrastructure?

The study aims to make the existing infrastructure more adaptive to sea level rise and future states of the delta by improving the context stage. Specifically, the decisions over the renewal, renovation, and replacement of infrastructure. A framework to set the context stage of the decision-making process is introduced. It consists of six steps that aim to strengthen the effectiveness of the decision process regarding the renewal and renovation of delta infrastructure.

The resulting framework emphasizes the importance of zooming in to improve the context stage and integrate the life cycle management and shows an iterative way to improve the context stage in case of disagreement on the definition of success between different stakeholders and disciplines. Furthermore, the framework includes understanding the influence of drivers and the order of priorities to minimize uncertainty by integrating long-term planning into social and political contexts to avoid radical changes in the future. The study attempts to include these different steps in the context stage within other steps that already exist in the methods. The suggested steps can be considered as a trial to interconnect the infrastructure with the changing factors on the political, social, and economical levels. Redesigning delta infrastructure requires an integral approach to comprehending different aspects that play a role in handling deep uncertainty in the future.

The following answers to the three sub-questions illustrate more the framework's role in the redesigning delta:

1. What are the decision-making under deep uncertainty methods (DMDU) and to what extent do they consider uncertainty over sea level rise and future states of the delta?

To deal with the changes in the future, several methods have been developed as tools to achieve long-term objectives under conditions of deep uncertainty. These methods are called decision-making under deep uncertainty DMDU. The study dealt with three DMDU methods, Robust Decision-Making (RDM), Dynamic Adaptive Policy (DAP), and Dynamic Adaptive Policy Pathways (DAPP). The reason behind selecting three specific methods from the DMDU family is the three methods have the same origin, which makes it easy to suggest coherent and consistent improvements for the context stage. Although the three methods have differences in operationalization, they start from the same basics and initial plans. There are other DMDU methods like the Info-Gab decision (IG) method and Engineering Options Analysis (EOA), these two methods depend on a different framework to handle deep uncertainty. IG depends on modeling the uncertainty in the beginning and then using the model to test the performance of a set of alternatives over a range of uncertainties, so it is difficult to model the uncertainty without expertise in this domain. EOA focuses on the technical systems more than adaptive strategies which narrow the scope of the EOI compared to other DMDU Methods (Marchau et al., 2019).

The three studied methods have a context stage. RDM's context stage is limited to general elements, whereas DAPP and DAP include more specific steps to scope the system. Each method has limitations in some respects. The literature review is done to compare these three methods and explained the weaknesses and strengths generally and specifically for four criteria, political uncertainty, social uncertainty, tipping points, and assumptions. The study contributes to highlighting the importance of integrating social and political contexts into the decision-making process. It addresses to what extent each method has limitations regarding these contexts. What can be concluded, DAPP is considered a good option to start reformulating the context stage because it meets all requirements to set an adaptive plan, but it oversimplifies interconnection between the system elements and drivers, which could lead to misunderstanding actions' consequences. Therefore, a comparison between the three methods is made to develop a framework that combines all strengths and handles the weaknesses of the three methods.

2. What are the different functions of the Eastern Scheldt barrier system and how are they affected by the drivers?

The study attempts to illustrate the role of hydraulic structures within the water management network and outlines the four directions of solutions for the southwest delta, open state, close, moving along, and seawards. Eastern Scheldt as a system is studied, and the external drivers that directly and indirectly affect the technical and functional performance are addressed to understand the relation between the drivers and functions. The study provides a new vision for the relationship between socioeconomic drivers and functions and how they influence each other. Also, it classifies the drivers based on their influences. Analysis of Eastern Scheldt functions in different scenarios of sea level rise and future states of Delta is carried out to illustrate the degree of complexity between three drivers, biophysical driver, socio-economic driver, and deterioration driver. What can be concluded, the interaction and the two-direction impact between drivers and functions are complicated, and it is difficult to estimate the timing of tipping points because that depends on several drivers at the same time.

3. What are the steps to improve the decision context for decision-making?

Based on the findings of interviews and the two previous questions, six steps are suggested, zoom in, understand the drivers, determine priorities, consolidate investments, integrate life cycle management, and define success. These steps aim to enhance the shortcomings of the three DMDU methods and to recognize the complexity of system interconnections. Each step represents a perspective to study the infrastructure and determine the priorities step is to integrate the policy arena into the context stage and understand the driver step is to relate the technical aspect with social context. consolidate investment step seeks economic opportunities. Integrate life cycle management step aims to relate all these previous aspects to the technical one to establish an infrastructure that considers changing factors in different contexts. Zoom-in step represents the key entrance to the stage because it aids in considering the requirements and identifying the vulnerability and opportunity of the structure accurately. Lastly, define the success step is to reach a consensus among the stakeholders over all previous processes and to determine whether they are appropriate and strategically and operationally feasible.

Limitations

- Simplicity

The three methods depend on modeling, especially RDM. Because of time constraints and lack of expertise in modeling, a simple analysis for Eastern Scheldt was carried out. Therefore, this analysis does not depend on accurate information, the aim is to clarify the idea of interdependence between the drivers and the state of Eastern Scheldt system in five different states and for methods development. Experts and specialists in hydraulic structures and policymaking in this domain have a broader knowledge of the technical details. Thus, more research is needed on the tipping points of the Eastern Scheldt barrier.

- Fragmented literature

Although the literature on DMDU has been growing, it is fragmented and incoherent in some points, which formed a challenge to understand each method correctly. In addition, many perspectives deal with a comparison between the methods, in addition to the big discussion over the effectiveness and degree of success of these methods, so following the literature discussion for the non-specialist is challenging.

- Qualitative analysis

This study depended on estimated values for the tipping points in the analysis of the Eastern Scheldt system, which means that not all inputs for results represent reality. In the qualitative analysis of this study, more technical details were necessary to go further in deep, especially in terms of life cycle management points. Although some studies and reports provide technical information about Eastern Scheldt, processing and employing this information is difficult for a non-specialist.

- Application of the methods

The study set a theoretical framework without implementing it and testing its effectiveness because of the constraints that are mentioned before. it also neglects how to make an overall plan for the water management network in the southwest of the delta including the state of Eastern Scheldt and what are constraints of zooming in the system are. Adaptation pathways are needed to generate, and also scenario discovery to test the context stage if it is effective or not.

Recommendations

- Additional research is recommended to apply the models practically and highlight the weaknesses of the improvements in the context stage. this study is conducted on a specific infrastructure, so a study for different cases to improve the context stage is needed with more practical applications.
- The socio-economic drivers in this study are limited and do not represent reality. Therefore, a wider study of various socio-economic drivers is needed and also drivers in the policy arena and how politics drive the long-term planning for the water infrastructure network.
- To prove the effectiveness of the improvements in the context stage, more real case studies are needed with more illustrative examples. In addition, it is important to broaden the use of DMDU methods to reinforce the understanding of the decision-making process.
- The thesis focuses only on the sea level rise as a consequence of climate change. It is recommended to study the other impacts of climate change on infrastructure like the change in river discharges.
- It is recommended to analyze other structures outside the Netherlands, in delta areas from different parts of the world to broaden the context of the research.
- Other assets like bridges, roads, and tunnels are recommended to study as follow-up research for decision-making methods.
- More research is recommended for studying the implementation time for actions. If the sea level rises quicker than expected and actions take a longer time to be implemented, overlapping between the impacts and actions can happen, and this point requires more research.
- More research is recommended to simplify the decision-making methods for long-term planning. The structure of the studied methods is complicated and could lead to misunderstanding the steps.
- It would be feasible to research the economy of the delta area to evaluate the opportunity for new housing projects, new agriculture investments, and recreation activities. The results may be valuable to understand the socio-economic drivers.

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Appendix A: DAP application

Application of DAP (Marchau et al., 2019)

Stage I, II

Initial plan				
Type of driver	Type of ISA	Action	Definition of success	Constraints
Phase I (2009–2012)				
Compliant driver	Warning ISA (speed alert)	• Start a campaign aimed at persuading people to turn on the speed alert functionality on their navigation device • Make agreements with companies that develop navigation devices	• Before 2013: 50% of the people that own and use a navigation device actively use the speed alert functionality	• Budget for a campaign
Less compliant and compliant driver	Free to be selected	• Develop a business case with insurance companies and lease companies	• Before 2013: 50% of the car owners and 50% of lease drivers can choose insurance or lease a product that involves ISA	
Notorious speed offender	Restricting ISA	• Perform a pilot test aimed at assessing the effects of implementing a restricting ISA for notorious speed offenders • Make an evidence-based decision regarding implementation of such a system for notorious speed offenders	• Before 2013: A decision has to be made on implementation of ISA for notorious speed offenders, based on, among others, the outcomes of the pilot test	• Budget/time
Phase II (beginning in 2013) will be dependent on the results of Phase I. For this phase, more restricting types of ISA will be considered				

stages III

Vulnerabilities (V) and Opportunities (O)	Hedging (H), Mitigating (M), Seizing (S), and Exploiting (E) actions
V: Implementing a restricting ISA for notorious speed offenders will damage the image of the less intervening ISA systems. ISA will be associated with punishment not with assistance (as it is now)	H: Decouple the pilot from the rest of the initial plan, and avoid the term ISA (currently done by calling it speed-lock)
V: The availability of an accurate speed limit database. Speed limit data have to be correct for right time (dynamic), the right location, and the right vehicle	This is a certain vulnerability, so: M: Define and apportion responsibilities before starting with implementation M: Issue a request for bids for the development of a speed limit database (this should be arranged by public authorities) M: Guarantee quality through a third party that is under the supervision of the public authorities M: Develop a system based on beacons that overrule the static speed limit information (failsafe design)
V: Automotive lobby will oppose the large-scale implementation of ISA	H: Include automobile manufacturers in the implementation strategy

(continued)

V: Speed limit data change more frequently than expected (by time and location)	H: Implement ISA systems that are robust against this situation (i.e., systems that allow for communication with the infrastructure, to transmit temporary speed limits—e.g., radio, Bluetooth)
O: Cars and ISA draw lots of attention and appeal to people's emotions. Instead of seeing this as a threat, this can be used as an opportunity	S: Invite stakeholders that have positive feelings about ISA to participate in improving and implementing ISA (e.g., the presenters of Top Gear, race drivers)
O: People/companies are more willing to adopt a technology if they can see the technology in practice. Creating a pool of cars that are equipped can result in an uptake of the technology	S: Practice what you preach. Let the Ministry equip its fleet with ISA to set an example. Prove that ISA can significantly reduce the number of accidents and can result in fewer insurance claims

Stage V, IV

Vulnerabilities (V) and Opportunities (O)	Monitoring and triggering system	Actions: Reassessment (R), Corrective (CR), Defensive (D), and Capitalizing (CP)
V: Implementing a restricting ISA for notorious speed offenders will damage the image of the less obtrusive ISA systems. ISA will be associated with punishment not with assistance (as it is now)	Monitor the: • Number of negative press publications • Level of acceptance of different ISA systems • Number and type of ISA-related questions asked of politicians in the lower house	D: Media campaigns to manage the perception of people regarding ISA (and the speed-lock); explain the difference and the need for implementing such an ISA for this type of driver
V: The availability of an accurate speed limit database. Speed limit data have to be correct for the right time (dynamic), the right location, and the right vehicle	Monitor the: • Level of accuracy/reliability of speed limit database	D: Initiate database accuracy enhancement CR: Stop implementation of certain types of ISA or combine with on/off switch and overruling possibilities CR: Design the system in such a way that it only warns/intervenes in areas with certain accuracy levels
V: Technology can fail: • Location determination can be inaccurate (e.g., in tunnels, in cities with high buildings) • Systems can stop functioning (sensors fail, etc.)	Monitor the: • Cause of accidents (relationship ISA—cause of accident) • Press releases on ISA and accidents	D: Make sure the market improves the systems (adjust implemented rules and regulations regarding system functioning) R: When large-scale failure occurs or the effects are drastic (ISA implementation leads to fatalities)

(continued)

Vulnerabilities (V) and Opportunities (O)	Monitoring and triggering system	Actions: Reassessment (R), Corrective (CR), Defensive (D), and Capitalizing (CP)
O: ISA implementation can result in larger cost savings than expected, lower and more homogeneous speeds, lower consumption costs (fuel savings + lower maintenance), resulting in higher levels of acceptance	Monitor additional effects of implementation on: • Emissions • Fuel use • Throughput/congestion	CP: Increase the number of participating insurance companies CP: Use this information in the business case for new insurance and lease companies
V: Speed limit data become more and more dynamic	Monitor the: • Availability of dynamic speed limits	D: Make sure road authorities equip new dynamic speed limit infrastructure with infra-to-vehicle communication (so in-vehicle systems can be easily adjusted) D: Standardize communication protocols and communication standards