ERASMUS UNIVERSITY ROTTERDAM Erasmus School of Economics

Master Thesis Economics & Business: Urban, Port and Transport Economics

Riding the wave?

An analysis of sea level rise adaptation in a broader welfare perspective

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Abstract

Sea level rise is a problem that the Netherlands will have to deal with in the coming century and can have significant economic consequences. In previous literature, this has been recognized but often the effects of only some of the consequences of sea level rise are analysed. Besides, adaptation to sea level rise often is not considered, although this is the first response of human beings in hazardous situations. Furthermore, sea level rise has many side effects on broader economic themes such as housing and government trust. This thesis tries to capture these effects on the broader economic welfare in the Netherlands in different adaptation scenarios. The problem of only using a narrow definition of welfare in the analysis towards sea level rise and the options of adapting to it is addressed. The research question posed is:

What broader welfare dimensions will be impacted by varying strategies of adaptation towards sea level rise in the Netherlands, and can a preferred strategy for the Dutch people be identified based on this?

Using a multi-criteria analysis approach with the dimensions of broader welfare as criteria, and preferences of the Dutch people as weights, it is shown that, for two contexts, two different adaptation methods are preferred to cope with the effects of sea level rise. Also, these preferred adaptation strategies are different from the preferable strategy in a narrow definition of welfare. This shows that considering broader welfare dimensions can influence the discussion of adaptation methods to sea level rise. The preferred strategy may however also be influenced by the context and preferences of economic actors in terms of broader welfare dimensions. This thesis suggests a toolkit towards a more integral analysis of sea level rise and adaptation options in the context of the Netherlands that other researchers and policymakers could take into consideration. Future researches could fill up the knowledge gaps of broader welfare dimensions' preferences and how to causally quantify the effects of sea level rise on broader welfare dimensions.

Contents

1. Introduction

In the Netherlands, we have had a history of getting our feet wet and keeping them dry. In 1953 one of the largest natural disasters in Dutch history happened. A deadly combination of a heavy north-westerly storm and a springtide in the night of January 31 and February 1, caused a storm surge, which made the floods reach exceptional heights. About 1800 people were killed that night, and the total damage of the flood was estimated at 5.4 billion euros (Rijkswaterstaat, 2021). The high level of destruction this storm surge caused was due to the Dutch land being below sea level. 60% of the Netherlands could be inundated as a result of floods. For this reason, the Netherlands have been historically protected by dikes. However, due to a lack of care, they became brittle, and the second world war shifted priorities. As a result, in more than 150 places the dikes broke. As an answer to this preventable disaster, the Directorate-General for Public Works and Water Management (Rijkswaterstaat), built the Delta works. By cutting off the estuaries like the Oosterschelde with dams, the sea-exposed coastline was shortened from about 700 to 80 km and flood defences were installed. This way, major floods have been prevented from happening ever since.

In the United States (US), flooding has caused a lot of damage as well. For instance, In New Orleans, Hurricane Katrina landed on August 29, 2005. Three years later, Trouw (2008) investigated the status at the time and determined the effect of the hurricane. It was the most expensive natural disaster in the history of the US, with estimated damages of 81 billion dollars. A year after the storm, the US economy has absorbed the impacts on the national scale, however, on a local level in New Orleans, the impacts are still felt after years (Herman, 2006). Nevertheless, in the US, New Orleans is one of the only cities that protect against major flood risks. This is because in the US flood risk is not the responsibility of the government but citizens themselves. Due to this irresponsibility, natural disasters like hurricane Katrina can have large consequences. These consequences include the direct damages that the water caused, but also indirect effects. To illustrate this, three years after the hurricane, the number of homeless people in New Orleans has doubled, Katrina has wiped out 47% of its citizens, and the city has become considerably whiter, meaning that predominantly black people have fled the city. One can imagine the impact of a decrease of about half of the population on economic prosperity. From an economic perspective, this triggers many more consequences (Kok et al., 2007). For example, the dominance of older generations that returned (Groen & Polivka, 2010) and the slow restart of small businesses (Corey & Deitch, 2011).

The attitudes of countries toward flooding can be compiled in the Disaster Risk Management Cycle (DRM Cycle), which is presented in Figure 1 (Van Ackere et al., 2019). This figure distinguishes five phases in which the DRM cycle can be broken down, and is used to describe how countries cope with disasters: Prevention, Mitigation, Preparedness, Response and Recovery. The first two are distinctly different. Prevention means the prevention of damage caused by possible floods, for example, hard engineering options such as storm surge barriers or dikes. Mitigation means minimizing the effects of a flood when it does happen, for example by restricting building in flood-prone areas. In the Netherlands for example, if we look at history, especially Prevention plays a big role. In New Orleans, we have seen that risks of flooding were first accepted, and the prevention phase has been skipped. In the US, the risks are accounted for by individuals. For example, when one can afford it, personal mitigation steers individuals into buying homes in less flood-prone areas. This is why for example in flood-prone areas house prices in the US are already seen to be lower than in higher grounds (Bernstein et al., 2017), which is also a phenomenon in the Netherlands, but at a much lower rate (Bosker et al., 2018).

Figure 1; Disaster Risk Management Cycle

In the Netherlands, we are at the forefront of new plans to cope with the risk of flooding. Due to the greenhouse gas emissions, the average temperature on earth rises, causing the polar ice caps to melt. The water that is released into the seas causes the sea level to rise. This sea level rise (SLR) will cause multiple problems to the way the Dutch manage water. The Dutch flood protection programme will be based on a SLR that is prescribed in the Deltascenario, in which SLR is projected to be 15-40 cm in 2050 and 25-80 cm in 2100 (Wolters et al., 2018), but there are signals that SLR might turn out to be higher than thus expected (see Figure 2). In this context, the Ministry of Infrastructure and Water Management and the Delta Programme Commissioner issued a knowledge program to integrate the new knowledge about SLR into the Delta programme (Ministerie van Infrastructuur en Waterstaat, 2021). An exploration into the consequences of accelerated SLR on the Delta programme is compiled in a report by Deltares (Haasnoot et al., 2018). The effect of sea level rise most focused upon is increased flood risk. However, with an increase in seawater levels, also other consequences, such as coastal erosion and salinization arise.

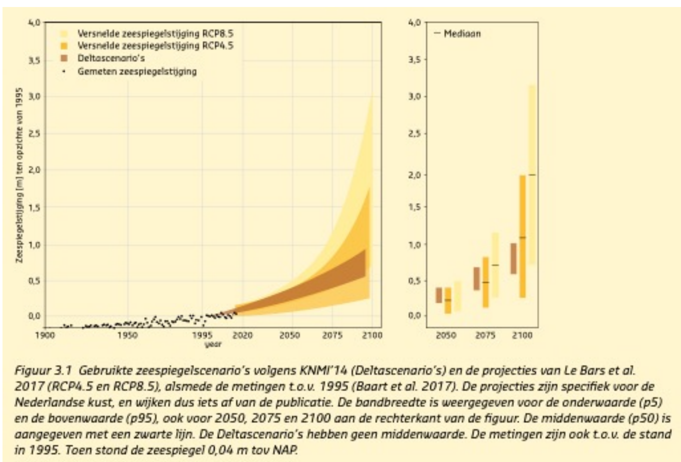


Figure 2; Projected sea level rises (Haasnoot et al., 2018)

To cope with the consequences of sea level rise, a simplified version of the DRM cycle is used to name three strategies in international literature: Protect, Accommodate and Retreat (IPCC CZMS, 1990). The starting point to cope with these effects in the Netherlands has often been the Prevention phase in the DRM cycle, in harmony with the Protect option. Flood protection for the Netherlands is guaranteed by the government by law. Every citizen has a prescribed safety level of at most a local individual risk of death as a result of a flood of 1/100,000 per year, meaning that for an individual there may be a chance no higher than 0.001% per year to die of floods (Rijkswaterstaat & STOWA, 2017). Countless studies have been performed from an engineer's perspective towards keeping these risks of flooding as small as possible. However, decreasing the risk of flooding only, ignores the Mitigation phase of the DRM cycle. This implies that there is relatively low attention to sea level rise in urban planning, which might cause problems in the future.

One of these problems is the fact that prevention can only be satisfied until a tipping point is reached (Kwadijk et al. 2010). For example, when SLR becomes too steep to cope with. Moreover, prevention will make flood protected areas safer, giving incentives to public and private investors to keep building societies in flood-prone areas. This moral hazard problem leads to more people locating in flood-prone areas, increasing the potential disaster costs (Husby et al., 2014). An indication of this future problem is also seen in the Netherlands. An example is the projected building of an entirely new village in the polder at the Netherlands' lowest point, which according to the Dutch Environmental Assessment Agency is an 'unfavourable location for investment' (NOS, 2021). Furthermore, according to Alex Hekman and Nikéh Booister from Sweco (2021), investments in housing, infrastructure, the energy transition, climate adaptation, agriculture, and nature, all of which are required to keep our country safe and livable in the future, do not or hardly take into account the future effects of SLR. Investments of € 900 billion up to 2050 require more than 100,000 hectares of space nationwide and thus largely determine the layout of our country. Given their lifespan, these investments might turn out to be inefficient with rising sea levels in the future. And even more severe, without considering the spatial needs to prevent the effects of SLR, spatial developments might conflict with further water safety adjustments. An example where this conflict is already occurring is Jakarta, Indonesia. Out of many options to prevent damages of SLR, in Jakarta, only the 'seaward' option remains economically viable, due to the economic value in the coastal area and resistance from the dense population (Sweco, 2021). Furthermore, Hekman (2021) points out that water safety issues are currently being addressed on a local scale, making it easy to justify protection, due to favourable cost-benefit evaluations. However, if policymakers begin to consider the long-term impacts of building in unfavourable sites on future generations on a systemic and broader level, establishing a new village in a low polder may become less appealing.

Based on the above-presented examples, it could be argued that an approach in line with the Mitigation phase of the DRM cycle might be more logical. However, this raises the question; what criteria should then be taken into account? The current research aims to provide an insight into this by presenting theories about the 'broader welfare'. Broader welfare can be defined as our current quality of life and the degree to which it is at the expense of generations after us or people in other parts of the world (CBS, 2021a) and could be useful to investigate the effects of SLR. Tol illustrate this, for the expected exponential rise of the sea level, the consequences will be minor now, but major on a longer timeframe (see Figure 2).

Furthermore, many of the effects of sea level rise and its adaptation options cause other effects on welfare dimensions that are much broader than for example GDP. This means that in the analysis of the effects of sea level rise and the role of adaptation towards it, broader welfare should be analysed instead of only a few of the dimensions of broader welfare.

Earlier research devoted attention to include more criteria in their analyses towards sea level rise, such as path dependency (Haasnoot, van Aalst et al. 2019), social vulnerability (Kind et al., 2019) second-order effects (Koks et al. 2014) or ecological systems (Brouwer & van Ek, 2004). However, others often only consider a few of the effects of sea level rise or the effects of sea level rise are only measured in a narrow definition of welfare, GDP. Nonetheless, there is also value in things that cannot be explicitly valued. Meaning that to disentangle the broader effect of sea level rise and adaptation to a country a broader definition of welfare is needed than GDP. Decisionmakers using this definition might form opinions that go beyond the acceptance of narrow welfare (GDP) policies. Future generations may benefit from decisions that seem inconceivable to us now. Therefore, the option that provides the greatest benefit to the broader welfare should be examined, and the analysis of sea level rise should be expanded.

In this thesis, the problem of only using a narrow definition of welfare in the analysis towards sea level rise and the options of adapting to it will be addressed. The current research suggests a toolkit towards a more integral analysis of sea level rise and adaptation options in the context of the Netherlands. Therefore, the following research question is put forward.

What broader welfare dimensions will be impacted by varying strategies of adaptation towards sea level rise in the Netherlands, and can a preferred strategy for the Dutch people be identified based on this?

To answer this rather complex research question, several sub-questions will be answered:

1. *What are the effects of sea level rise in general, that can lead to economic effects?*
2. *What are the options for adaptation towards sea level rise and which side-effects/barriers exist?*
3. *How do the dimensions of broader welfare in the Netherlands respond to different strategies of adaptation to sea level rise?*

Thus, this thesis aims to identify as many as possible direct and indirect effects of sea level rise. These effects will be coupled to the dimensions of broader welfare and visualized in a conceptual model showing these relationships. A multi criteria analysis will be employed to find the preferred option of adaptation to sea level rise, according to criteria that potentially impact the broader welfare and preferences of the Dutch.

The following chapter presents an outline of the literature on the assessment of sea level rise, showing what approaches economists use in the assessment of sea level rise and adaptation methods. Next, potential effects of sea level rise are identified, followed by their identifiable indirect effects to yield a conceptual model on how sea level rise and adaptation methods affect the Dutch economy. Next, the methodology of multi criteria analysis is explained, followed by the analysis itself. In the results section, results are elaborated, and the outcome of the analysis is shown. In the conclusion and discussion, the findings will be wound up, limitations will be addressed and recommendations for policy and future research will be proposed.

Before explaining each effect of SLR and adaptation strategies, this thesis will give a reading guideline, which is presented in Figure 3. To remain an overview of the effects discussed, a framework is used to structure this thesis and to guide the reader through the research.

The economic evaluation of SLR frequently only considers a few aspects of broader welfare. Also, only flooding is commonly used to estimate the economic impact of sea level rise. Furthermore, adaptation is sometimes overlooked while determining these consequences. A three-dimensional model will exhibit the breadth of SLR's effects in various scenarios to demonstrate how many other effects can occur as a result of SLR. In Figure 3 one can see the 'cube of SLR effects'. The goal of this thesis is to show that after addressing the current economic analysis towards SLR, many of the cubes' contents are missing. By building up the cube from the bottom-up, this thesis tries to determine which are the missing blocks.

In the cube on the X-axis, the effects that occur due to sea level rise are shown. These are determined in Chapter 2. In the cube on the Y-axis, the dimensions of broader welfare that are relevant to the effects of SLR are shown. These dimensions will be introduced in Chapter 4 and tested with the effects in different contexts in Chapter 5. In the cube on the Z-axis, the different strategies of adaptation are shown. In this case, 'SLR' refers to a situation in which protection levels are equal to those in the status quo but are influenced by SLR effects. Protect and Retreat refers to the use of the Protect and Retreat strategies, which are both addressed in paragraph 2.3.5.

The codes of the blocks will be used to structure dimensions, effects and strategies throughout this thesis. One should read the code as 'dimension'.'effect'.'strategy' (Y.X.Z). An example would be the effect of Migration on the Material welfare dimension in a Retreat scenario, coded by M.M.R. Potentially, 108 different effects can be described by the cube. However, likely many of the blocks will remain unfilled, as there are combinations of effects in scenarios that do not affect certain dimensions. For example, in a SLR scenario, where no adaptation is presumed, there will be no effects from adaptation. If an effect is not bound to one specific strategy, it will further be referred to as the code Y.X.

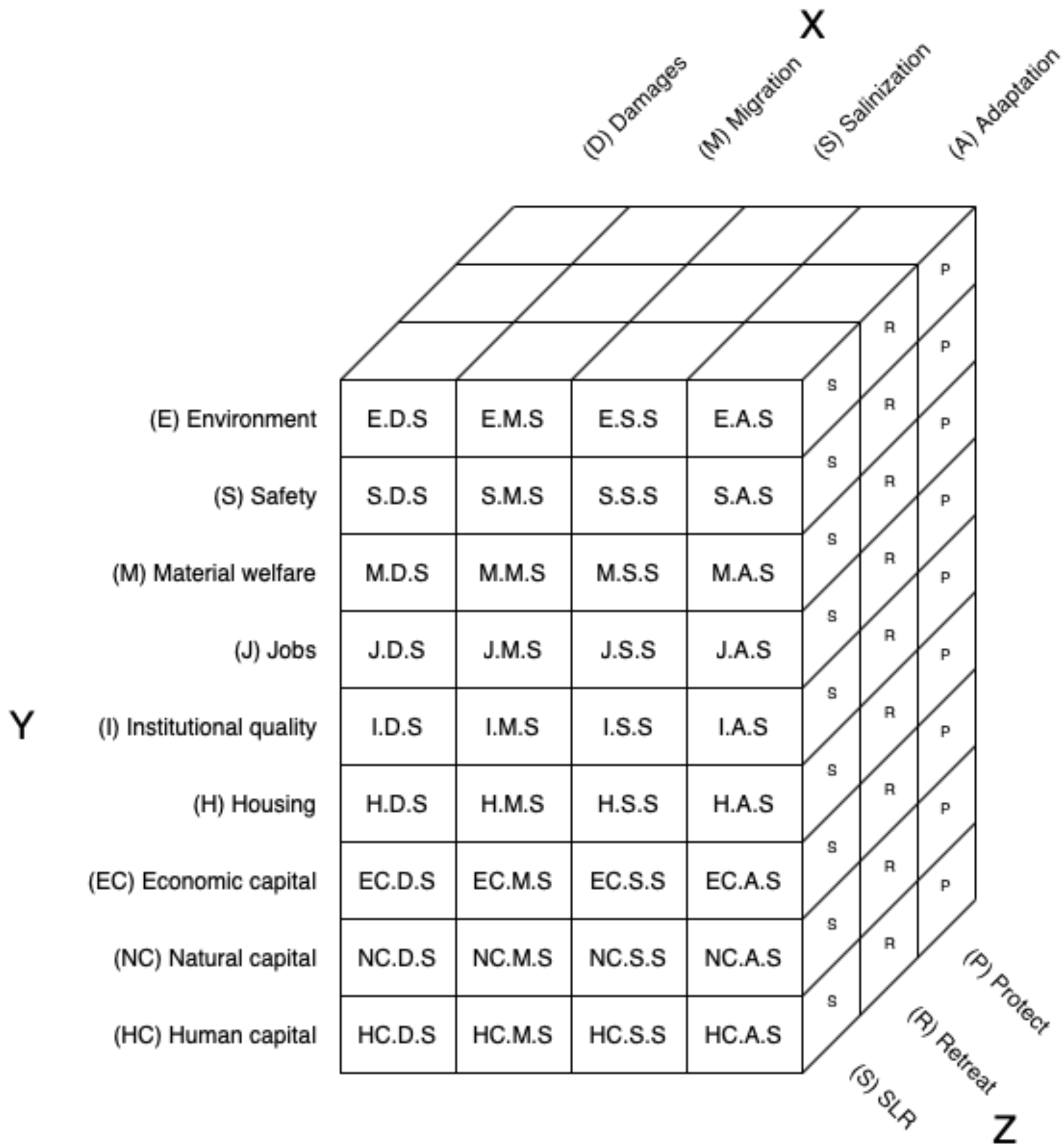


Figure 3; The cube of SLR effects

2. Literature review

2.1 Economic assessment of sea level rise

To reach an understanding of the methods and techniques previously employed in the assessment of sea level rise, this section explains the approaches that are used to calculate the economic losses of sea level rise. These techniques show that the assessment of an integrated economic effect of sea level rise is hard to reach, for example, because of a lack of detail, a lack of precision in estimating second-order effects and path dependency.

2.1.1 Exposure and vulnerability approaches

In exposure and vulnerability approaches, inundation depths resulting from floods are modelled on a local, regional or global scale. Inundation of certain land use, for example, residential or agricultural are translated into monetary units with a depth-damage curve. The principle of this calculation is shown in Figure 4 (Jonkman et al., 2004). Huizinga et al. (2017) provide a comprehensive global database of flood damage functions that can translate flood water levels into direct economic damage. For example, in Germany, the maximum damage that is estimated to occur to a square meter of residential surface in a building is €783. This maximum damage occurs when there is an inundation depth of 6 meters. When the depth is less, for example, 2 meters, a factor of 0.60 is used, resulting in damage of €469.8 per square meter. For less developed countries, e.g. Ghana, this maximum damage is €207 and with a factor of 0.67 for 2m inundation, €132.48 respectively. In many of these studies, adaptation is only used as an option to avoid costs of damage and not so much as a starting point of coping with sea level rise. This is why, for example, in flood-prone areas, house prices in the US are already seen to be lower than in higher grounds (Bernstein et al., 2017).

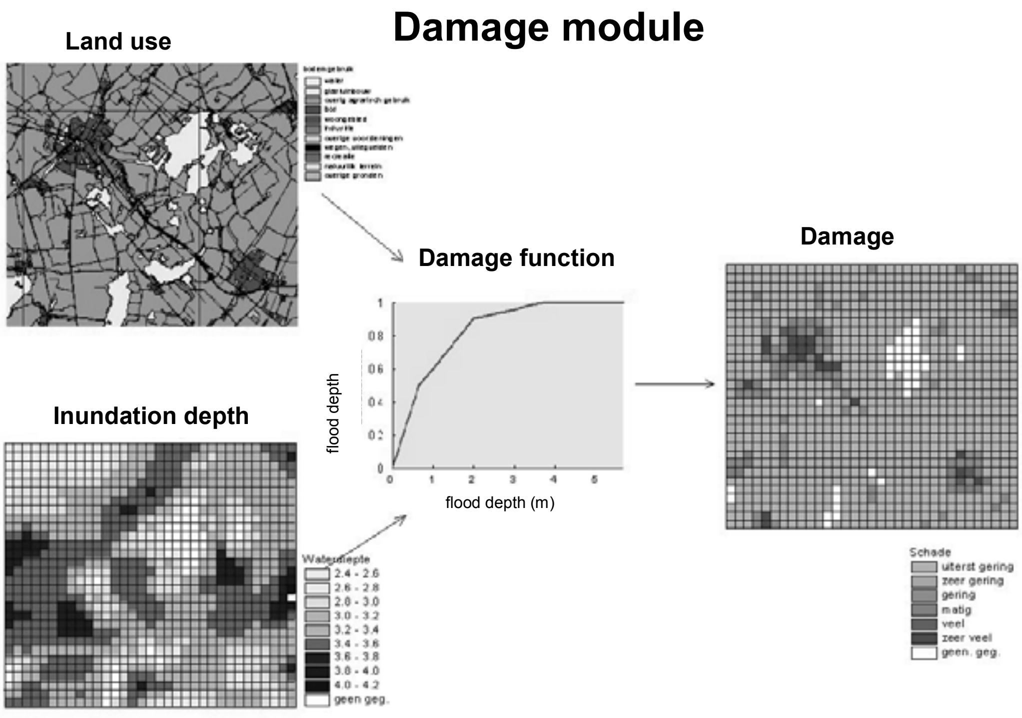


Figure 4; Principle of the method for assessment of economic damage

2.1.2 Top-down and bottom-up approaches

A distinction can be made also based on top-down or bottom-up approaches to the impact of SLR (Bosello & De Cian, 2014). Bottom-up approaches have been made based on different scales; global, regional and site-specific. Site-specific analyses are higher in detail than regional bottom-up studies. Bottom-up studies focus on exposure and vulnerability analyses and sometimes include cost-benefit assessments, but do not account for the feedback of SLR on macroeconomics and/or social context. Bottom-up approaches can integrate indirect effects of SLR on the rest of the economy only based on first-order effects. An example could be the displacement of people's housing, with its estimated cost. An example of a bottom-up approach for the case of the Netherlands is the VNK report (VNK2, 2014). In the Netherlands currently, the economic risks are very moderate because of the extensive water safety efforts.

Top-down approaches however include estimates of indirect costs caused by the first-order effects, which also entail costs that arise due to market-induced adjustments affecting income, GDP or welfare (Bosello & De Cian, 2014). Top-down models are generally less detailed in the spatial and technical description of the area assessed, but market interactions and growth effects are included. Where bottom-up approaches are thus highly efficient in estimating the costs and benefits of sea level rise and its adaptation measures but do lack indirect effects, top-down approaches are better in including indirect effects but are not able to integrate local spatial and technical specifications, which makes estimates on a local scale less accurate. Bottom-up studies can be complemented by top-down studies to reach a broader economic evaluation.

Efforts have been made to combine both bottom-up and top-down approaches into one. In research into the effects of SLR in Rotterdam, Koks et al. (2014) integrate direct and indirect flood risk modelling, by using both the bottom-up approach and a top-down approach in which the second-order effects are investigated by using a Cobb-Douglas production function to translate loss of capital and labour into production losses using an Input-Output (I-O) table. The advantage of this framework offered is that it requires only three inputs of data, making it widely applicable: an inundation map, a land-use map, and an I-O table (See Figure 5) (Koks et al., 2014).

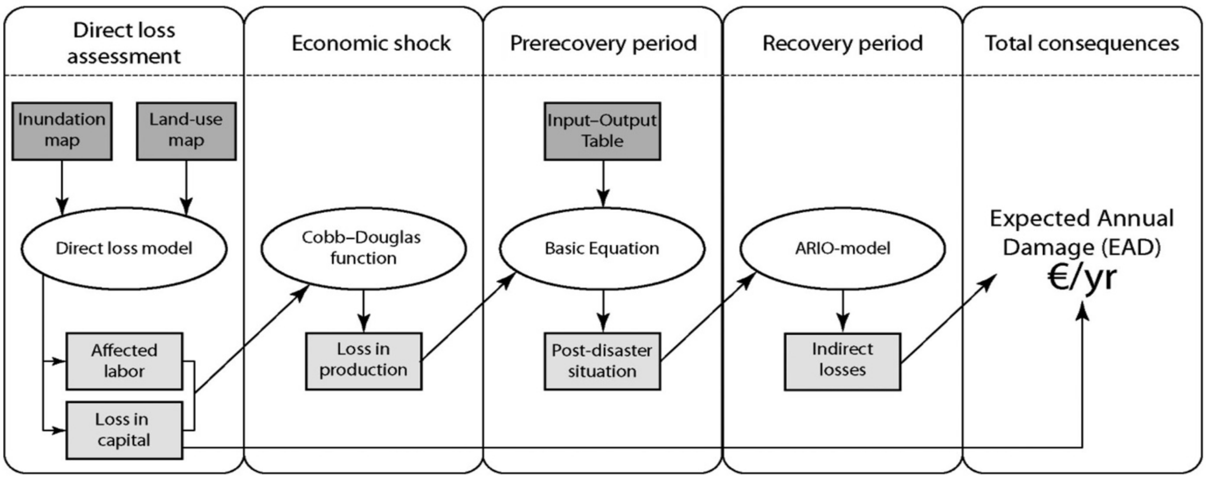


Figure 5; Overview of the different components of the framework. The dark gray squared boxes are the inputs, the ellipses are the different models, and the light gray squared boxes are the model outputs.

2.1.3 Path dependency

In the quest to find optimal adaptation to sea level rise, most modelling approaches miss the concept of path dependency (Haasnoot, van Aalst, et al., 2019). As put before, by engaging in a certain investment decision, for example building housing at a low point of the polder, a path dependency is initiated, meaning that this investment choice further influences the next sequence of investment choices, for instance, the decision to build a dam that increases the probability of flooding this polder. In Haasnoot, van Aalst, et al. (2019) this path dependency is considered by using a cost-benefit approach that is modified to include transfer costs. In their framework, different adaptation pathways can be compared in their costs and benefits along the timeframe of adaptation to be able to react based on 'adaptation tipping points' (Kwadijk et al., 2010) in the future. Adaptation tipping points are defined as 'points where the magnitude of change due to climate change or sea level rise is such that the current management strategy will no longer be able to meet the objectives. This gives information on whether and when a water management strategy may fail and other strategies are needed'. Examples often used in the context of sea level rise in the Netherlands is the closing frequency of the Maeslantkering, which protects against flooding, but when these floods happen too often also hinders maritime transport at an uneconomical level.

2.2 Sea level rise effects

In this section, the effects of sea level rise will be explored. This chapter is structured based on the X-axis of the cube of SLR, in Figure 3. This means that first, Damages will be discussed, then Migration, Salinization and Adaptation (see Figure 6).

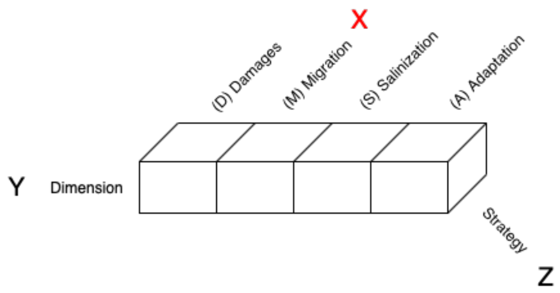


Figure 6; The X-axis of the cube

2.2.1 Physical effects of sea level rise

The main four biogeophysical effects of sea-level rise that occur are the inundation and displacement of wetlands and lowlands, exacerbation of flooding, salinization and coastal erosion (Bijlsma et al., 1996). There are also other effects of sea level rise that might turn out to have economic consequences, such as impacts on marine ecosystems and in turn industries like fisheries or non-use value of nature, such as sea bird habitat (Von Holle et al., 2019). Adaptation is the anthropogenic way of coping with these biogeophysical effects of sea level rise and plays an important role in the physical effects of sea level rise, as they have advantages on the one side, but might also cause other mechanisms to induce economic losses. Therefore, in these primary effects adaptation measures are included in this chapter as it is the first response to sea level rise. An illustration from Tol et al. (2008) shows why adaptation is this first response and belongs to the primary effects. 'To illustrate adaptation, consider a sandy beach on a sunny day. The beach is filled with sunbathers. Most people lie with their heads a few centimetres above the level of the sea. If the sea were 50 cm higher, they would all drown! That is, unless they adapt. There is little reason to doubt sunbathers will adapt. Sunbathers have eyes and ears and reasons to avoid drowning'.

2.2.2 Flooding & Coastal erosion

The two main types of flooding that occur increasingly due to sea level rise in particular are coastal floods and river floods. Coastal floods can happen through a storm surge or other weather-induced high water levels, that causes water to pile up against the coast and either damage the coast (coastal erosion) or overtop the coastal barriers and flow further inland than normal (flooding). Coastal flooding from storm surges will become more frequent with sea level rise (Dawson et al., 2009). Before flooding occurs also coastal damage is caused. This can be a continuous process but can also happen as an episodic event. The damage that is done to the coastline is known as coastal erosion, of which a picture can be seen in Figure 7. As the effects of flooding and coastal erosion are highly similar, this thesis will take the effects of the two together and further refer to flooding. Flooding, is, however, not exclusively a coastal problem. Due to sea level rise, the drainage capacity of rivers into seas decreases, which might cause rivers to leave their banks and inundate neighbouring areas. This is especially a problem in deltas and countries that lie below sea level.

Figure 7; Holiday housing abandoned due to coastal erosion in Yorkshire, UK (Halliday, 2020)

The obvious first effect of flooding is inundation, which can cause a lot of damage to structures, nature and people. These damages can be categorized in the cube (Figure 3) as H.D, E.D and S.D respectively. But more, less obvious effects can happen due to flooding. Firstly, the direct effects of flooding on the area that is flooded are specified. These are obtained from the widely used DIVA model for estimation of the direct costs of flooding using a bottom-up approach: 1) the costs of land loss, 2) the expected annual flood damages and 3) forced migration costs (Hinkel et al., 2010). Next, the effects that are indirectly involved with flooding are detailed.

Land loss

Land loss is the permanent abandonment of land that has been inundated. This can be due to the costs of reclaiming it being higher than the benefits of future use of the inundated land. The costs associated with land loss can be determined in various ways. First, the price of the land that has been inundated (M.D). Second, the production value of the land that has been inundated (EC.D). The price of the land that has been inundated often is overestimated due to its coastal nature. Being on the coast brings a lot of amenities to some land uses. For example, in an urban area, it is highly profitable to be located on a coast due to tourism and transport opportunities. More inland located urban areas miss these amenities and are thus valued at a lower rate. This means that when coastal areas are permanently inundated, the coastal and market price often is used. However, as Yohe (1991) put forward, compensation for this must be made because the coastline shifts inwards, making inland areas more valuable. So, sea level rise leads to a loss (from land loss) and gain (from additional amenities in farther-inland locations). Over the long term, when amenities have recovered in inland locations, the economic loss from permanent land loss needs to be calculated with inland market prices, much lower than coastal ones.

But besides value that is already priced into the land, which often only associated with the production or consumption value of land, there also exist many different ways in which land adds to overall welfare that are not priced in. An example of this is ecosystem value or natural capital (Hallegatte, 2012). Where land was also used to house trees and animals, with inundation these are replaced by water and water plants and fish. Trees on land contribute to society by offering nice views and the consumption of CO_2 emissions helps us reach climate goals. Fish however feed us and thus also offer value to society. These are called ecosystem services (E.D & NC.D). The net gain or loss can be calculated by assigning values to both situations, a practice that for the Dutch North Sea is performed in natural capital accounting of the Dutch Central Bureau of Statistics (Centraal Bureau voor de Statistiek, 2019). Besides these ecosystem services, that are beneficent to society, also other beneficiaries exist, such as nature itself. An example of this could be the submergence of an animal species that is not directly or indirectly involved with value creation for mankind. These impacts however cannot be priced, as humans are not able to determine what nature values about nature itself. For these kinds of impacts, a broader definition of welfare might be necessary.

The loss of land as a production or consumption factor also plays through into other regions and markets important for economic welfare. For example, land loss increases the scarcity of land, and thus land prices. This increase in land prices will find its way into costs for developers of new housing and thus housing prices (H.D). This effect on price from land loss can be explained from the DiPasquale & Wheaton (1992) framework for real estate assets and space in Figure 8, in the lower-left quadrant. Here if construction costs rise, the price of an asset will increase. It will also increase the costs of operating businesses that use the land as an input, such as agriculture, and also puts a strain on nature, as alternative uses become more valuable (NC.D).

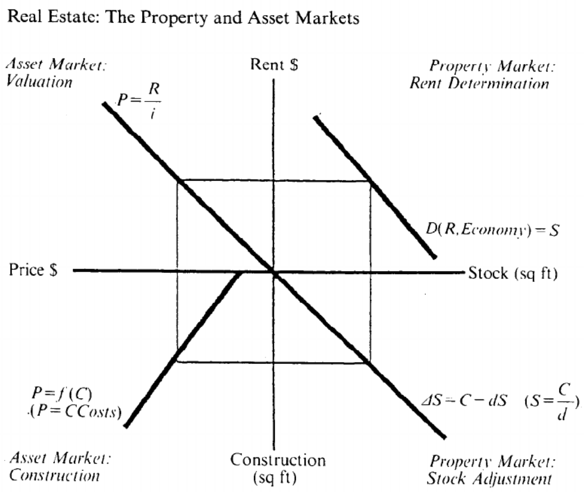


Figure 8; DiPasquale & Wheaton framework

In Louisiana (United States) where land loss is a recurring problem, another side effect of land loss is the effect that storms would have on businesses and homes further inland when there was less of a protective 'buffer zone' along the coast to protect those areas from storm damage (Environmental Defense Fund, 2017). Meaning that land loss becomes increasingly important when it is close to a large city, as its protective capacity decreases and thus flood risk increases.

Furthermore, the land loss might induce urban density. Based on logical reasoning, when a certain body of land becomes smaller while remaining its citizens, the body becomes more densely populated. This increased density in turn might increase the productivity of the citizens due to agglomeration effects, yielding a higher income and welfare level (M.D). However, increases in density might also have negative consequences such as pollution and congestion, which decrease the welfare level (E.D & NC.D). In economic modelling, the effect of density on welfare is thus ambiguous.

Flood damages

Besides the loss of land, further impacts of flooding include damages to structures, people and other entities that exist on land. For example, a car that is totalled by a tree falling due to a mud stream caused by the floods, but also losses of life that occur in a flood event. Often these damages or losses are measured based on market prices. For life however, other valuation techniques are used. In practice, this comes down to the value of a statistical life (VSL). For the context of flooding Bockarjova et al. (2012) find this value to be about 6.3-7.2 million euros per additional statistical life saved, or fatality avoided (S.D). Besides the loss of life, inconveniences of evacuation and injuries can also be valued. In the case of flooding in the Netherlands, Bockarjova et al. (2012) find values of 2,300-2,500 euros per evacuation (VOSE) and value of statistical injury (VOSI) of 91,000-102,000 euros (S.D & M.D).

Flood modelling previously only took into account areas that are explicitly inundated by sea levels, but often damages are not limited to only the low-lying areas. Sea level rise also increases the frequency of episodic events of flooding, such as hurricanes and storm surges and thus increases also the risk of damaging areas that are not inundated. Michael (2007) estimates that in a 3-ft (91cm) sea-level rise scenario, damage from episodic flooding is 9 times as large as the estimated loss from complete inundation. Under a 2-ft (61cm) sea-level rise scenario episodic flooding damage is 28 times greater. This means that the risk of flooding is not limited to inundated areas. This is why the term 'flood risk' is currently often used to denominate the annual expected damage (AED) costs of flooding events (M.D). This annual expected damage is calculated by assigning a probability to a flooding event, multiplying this by the damages of this flooding event and compounding these into an expected annual damage curve. In which the steps follow steps 1, 2 and 3 in Figure 9.

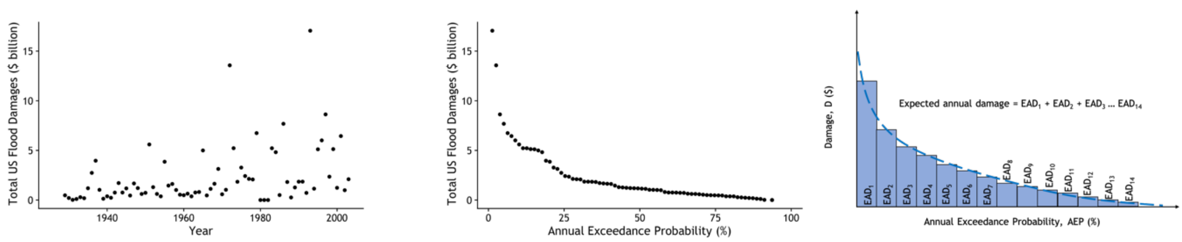


Figure 9; Step 1, 2 and 3 in Expected Annual Damage calculation, adapted from Colorado Water Conservation Board (2020)

Mapping of these costs results in a flood risk map, of which an example is shown in Figure 10 from the Flood Risk in the Netherlands project (VNK2, 2014).

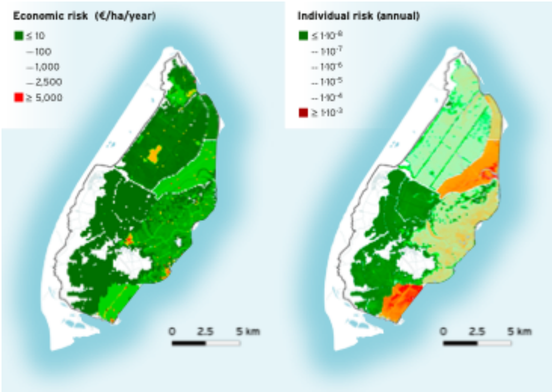


Figure 10; Expected annual damage of flooding in Texel, the Netherlands

In the context of coastal erosion, in particular, tourism and industry play a big role. Many of the world's favourite tourism locations are to be found on countries' shorelines. Furthermore, due to the transport opportunities, many of the worlds industrial sites are found in harbours that are located on the coast. The indirect effects of coastal erosion are thus characterized by a high vulnerability of industry and tourism (M.D). But besides the damages to sectors done, also investment comes to a halt due to coastal erosion (EC.D). Public infrastructure investment in vulnerable coastal areas is risky, and the benefits short-lived. An example of an investment that was swallowed by the sea is the Abidjan-Lagos highway in Togo. It was supposed to be a vital artery for economic development and integration in West Africa and has already been rebuilt twice (Kemper, 2017). This shows how investment in risky coastal areas is not efficient. Investors will also notice this and shift their money elsewhere. The study of Jongman et al. (2014) even argues that the increased share of economic value located in potential flood-prone areas can harm the feasibility of private insurance schemes in the Netherlands (EC.D).

Table 1; Direct and indirect damages of flooding in Rotterdam (adapted from Koks et al., 2014)

Return period	**Direct losses (in € billions)**	**Indirect losses (in € billions)**
1/10	0.22	0.13
1/100	0.44	0.29
1/1,000	0.76	0.61
1/2,000	0.92	0.83
1/4,000	1.10	1.14
1/10,000	1.88	2.51
EAD (million Euro/year)	36.1	23.4

The indirect effects of flood damages have been studied by making estimates of second-order effects of losses in capital, land and labour in input-output (I-O) models and computable general equilibrium (CGE) models. In these models, estimates of a cascade of impacts along supply chains are made (M.D & EC.D). These I-O models suggest that in Rotterdam the direct impact of flood damages needs to be multiplied by a factor of about 1.6 to reach the impacts over the whole supply chain (see Table 1). I-O models generally overestimate the further-order effects and CGE underestimates these. For instance, I-O modelling may result in overestimation of the effects in the non-affected regions because it doesn't consider the substitution possibilities between the imports from different regions and CGE-models have the potential to underestimate because of possible extreme substitution effects and price changes in the short-run (Koks et al., 2014).

Assumptions about substitution, or trade, heavily influence the estimation of indirect losses of flooding. In Koks (2016) four top-down models are run for a flooding event in Emilia-Romagna in Italy. Two of these models, the ARIO and MRIA, are I-O models. In his comparison, Koks (2016) also considers two types of CGE based models. The results, shown in Figure 11, show that assumptions for substitution differing between models can heavily influence results. For example, in the bottom-left corner, both the affected region and unaffected regions are impacted, because trade is restricted. When trade is not restricted, for example in the bottom-right of Figure 11, only the region affected incurs losses, while the others benefit from increased demand of production factors. However, in a real disaster situation, regions do likely suffer from barriers to trade and movements of production factors.

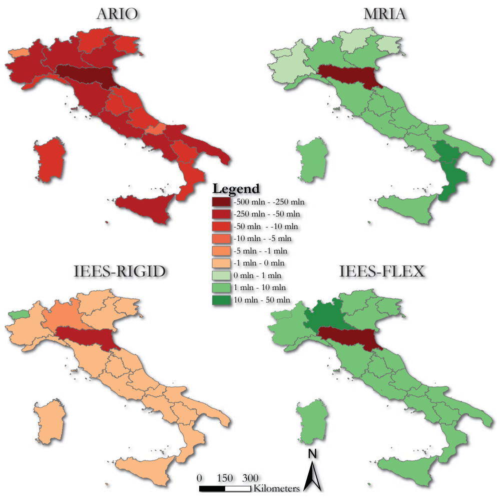


Figure 11; Prediction of losses in Italy for a flood in Emilia-Romagna for four model setups.

Besides measuring production losses due to flooding, according to Koks (2016), these also have important implications for public budgeting. For example, production losses lead to lower tax revenues, and disaster recovery programs lead to larger public spending and government debt (EC.D). This higher-order effect, the loss of tax revenues, can be seen as a depressant on demand for final goods as seen in Figure 12. The income of households decreases, depressing income taxes, decreasing government expenditures, savings and investments, and in turn decreasing the demand for products. In the end, this might lead to lower production, less income to factors of production and so forth, leading to a vicious cycle of what is known as a recession (EC.D, M.D, J.D).

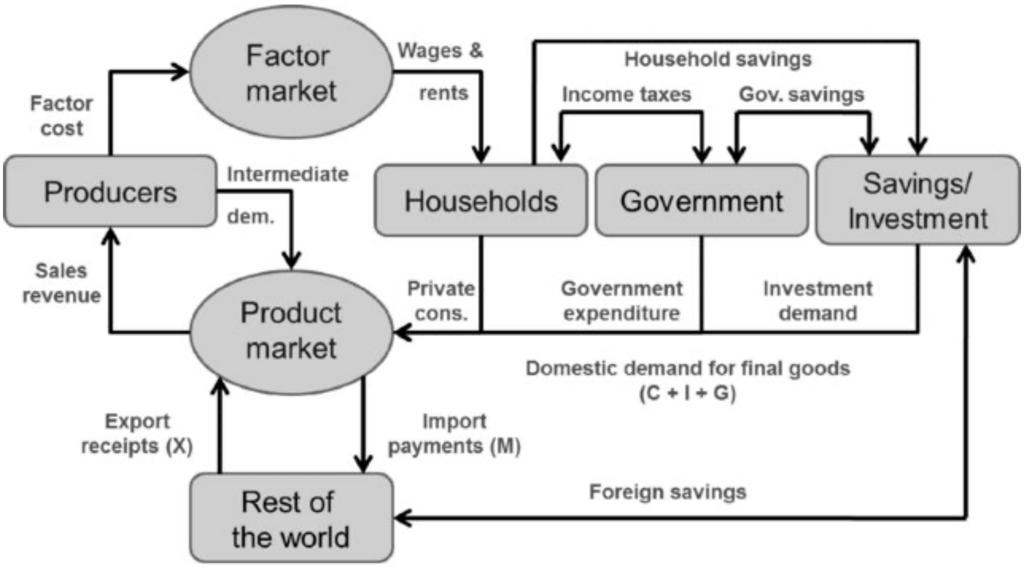


Figure 12; the Circular flow of income in an economy (Nielsen et al., 2015)

Forced migration

Many scholars have included mass migration in the impacts of climate change (Lonergan, 1998). While many of these studies have based their assumptions of forced migration due to climate change or sea level rise on common sense, Perch-Nielsen et al. (2008) try to include an empirical basis to this link between migration and floods and sea level rise. They suggest that although mass displacement after a natural disaster event is a common phenomenon, mass migration of the permanent type does not take place to a large extent. Only up to 30% of the people that migrate due to SLR, are affected so badly that they migrate permanently. Migration is especially coupled to damage to housing and infrastructure combined with a reduced income and in places where out-migration was already happening before floods. The highest rate of migration is due to riverbank erosion that cuts grounds from under the inhabitants' feet. A conceptual model that explains how climate change, and in turn sea level rise causes migration can be found in Figure 13 (Perch-Nielsen et al., 2008).

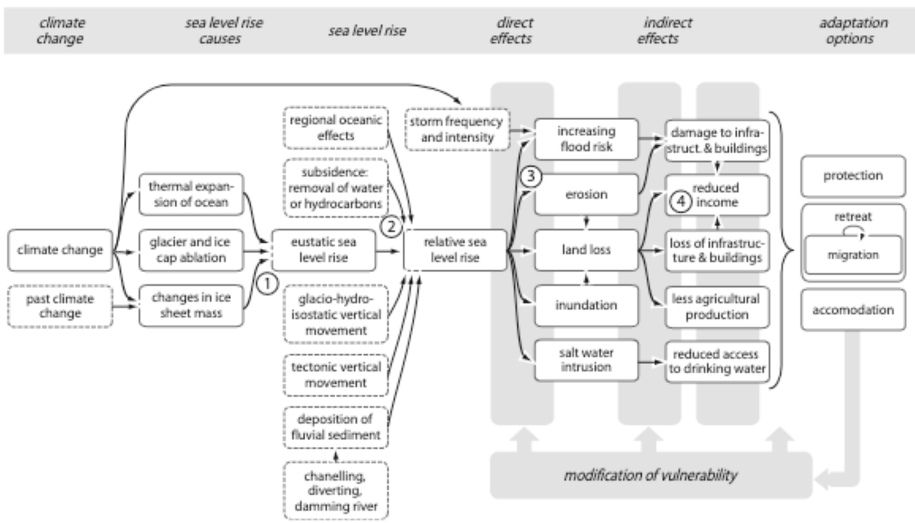


Figure 13; Conceptual model of the influence of climate change on migration through sea level rise (Influences vary in strength. Boxes with dashed lines are external factors)

Black et al. (2011) extend the literature on the environmental causes of migration with their conceptual framework which especially focuses on the decision whether to migrate or stay and adapt. This framework (Figure 14) shows that many characteristics influence this decision.

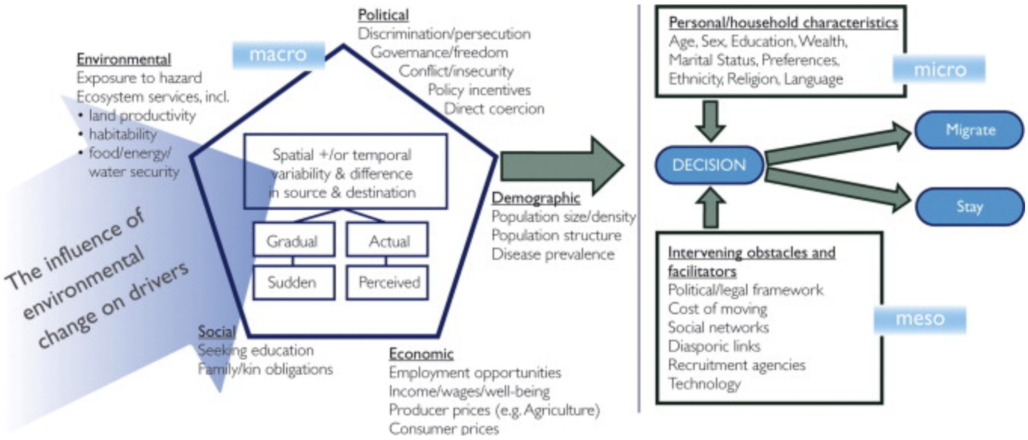


Figure 14; A conceptual framework for the 'drivers of migration' (Black et al. 2011).

Hauer (2017) tries to model this migration in the United States and answers the research question 'What areas are likely to see the greatest in-migration due to SLR?' and stresses that the affected areas of SLR are not limited to the coastal area. When migration is accounted for, SLR affects landlocked areas of a country too, due to influx of migrants. His approach builds on the growing literature concerning migrant destinations and environmental change and uses, as determinants of attractiveness to potential migrants the 6 principles of Findlay (2011) (Table 2). He shows that the cities, which are most likely to see an influx are Austin TX, Houston TX, Orlando FL, Palm Beach FL, Los Angeles CA and Baton Rouge LA, based on previous migration patterns. To make this influx possible, however, these migrants also require adequate infrastructure to accommodate them. Hauer doubts that this is the case for these cities.

Hauer assumes that only high-income households (>US$100,000) will stay in coastal regions. However, research about the relation of migration to sea level rise shows that higher-skilled workers migrate disproportionally to low-skilled workers, meaning a flight of human capital as suggested by Zissimopoulos and Karoly (2007) (HC.2). Also, the IPCC (2014) claims that low-income households will likely stay despite their high vulnerability because their ability to move is low — they are a 'trapped population' (Adger et al., 2014). In addition, Hauer omits the fact that most urban centres already have adapted to SLR (Aerts, 2017).

Table 2; Six principles governing the attraction of places to potential migrants (Findlay, 2011).

1. Most potential migrants want, if at all possible, to stay in their current place of residence, even although economic and social metrics might suggest that there are external gains to be achieved by moving. This is sometimes referred to as 'the immobility paradox'
2. Once a decision to move has been taken, there is an almost immutable law that most people move over short distances rather than longer distances. And places with large populations have greater interaction with each other than those with fewer people

3. Potential migrants often do not move to the most attractive possible destination but if they move (given principle 1) they end up working or living at a nearer rather than more distant place simply because it represents an 'intervening opportunity'
4. The relative attraction of a range of destinations can be interpreted in economic terms, such as the increased income that it offers (in terms of wages) or benefits (in terms of returns to 'human capital') that can be derived from moving there.
5. The selection of migrant destinations is to some extent shaped by pre-existing social and cultural connections, which some researchers have used to explain the uneven attraction of places within a 'transnational social field'.
6. It is increasingly recognized that places are viewed as attractive because of the 'social' and 'cultural capital' that they may offer, and not only because of possibilities for immediate financial gain.

Perch-Nielsen et al. (2008) and Black et al. (2011) conceptualize the possibility that the effects of flooding cause migration. Both show the factors that contribute to outmigration. What the implications of outmigration are is another line of research. In the International Monetary Fund's World Economic Outlook (IMF, 2020), a chapter is dedicated to the macroeconomic effects of immigration. In Figure 15, the consistent positive effect of immigration on economic indicators is summarized (M.M, J.M, EC.M, HC.M). One of the causes of the positive effects of immigration on the economy of receiving countries is the complementarity of native and immigrant workers. When immigrant workers enter the labour market, they tend to go into jobs that do not require linguistic or communicational skills. Natives then can earn higher wages by upgrading to a higher productivity job, where they might perform more specialized tasks (HC.M). This increase in specialization yields gains to productivity and so forth on other economic indicators (M.M, J.M, EC.M). Many studies, including Peri & Sparber (2009), Hunt & Gauthier-Loiselle (2010), and Cattaneo et al., have employed this mechanism to explain gains from immigration (2015).

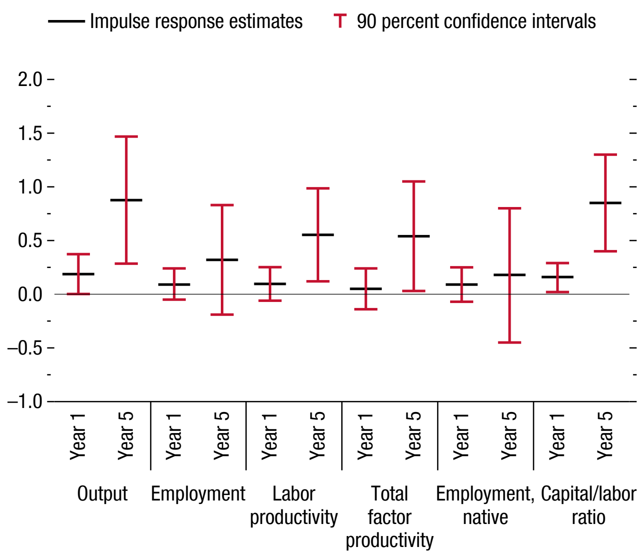


Figure 15; Macroeconomic response to a 1 percentage point increase in the ratio of the immigrant flow relative to total employment in Advanced Economies (IMF, 2020)

However, to this upside in the receiving country or region, the opposite effect happens in the sending country. Where mostly higher educated people will be most incentivized to move from the affected area to another area, the sending area might experience a so-called 'brain drain' (HC.M) leading to a loss in productivity (M.M), but may also experience positive network externalities (Docquier & Rapoport, 2012) (M.M). Also, sending regions can experience monetary benefits of outmigration such as remittances and investment in education (Bana, 2016) (M.M, EC.M, HC.M). Remittances to the sending country can serve as an additional national income. A case where this is substantial is the Philippines, where remittances account for nearly 10% of GDP (World Bank, n.d.).

Another effect that is caused by emigration is the fact that people move out of houses. While people move out of a region that is afflicted by SLR, demand for housing and public infrastructure decreases (H.M). House prices will go down further and public investments come to a stop, decreasing the attractiveness of the region to settle or establish a business (M.M, J.M, EC.M). There are already signs of decreases in amenity value and house prices in regions of shrinkage in the Netherlands (ABF Research, 2019). Due to SLR-induced emigration, this effect will likely increase.

Another side-effect of outmigration in regions that suffer substantially from sea level rise can be reduced trust and social capital. Regions that suffer from population decline and neglect from government and private sector investments tend to end up being more extremist in their beliefs and voting behaviour (I.M, S.M). According to Rodríguez-Pose's 'Revenge of the places that don't matter' (2018), these regions are 'surfing the wave of populism and, through the ballot box or revolt, attacking the very factors on which recent economic growth has been based: open markets, migration, economic integration, and globalization' (M.M, J.M, EC.M, HC.M).

2.2.3 Salinization

Soil salinization is defined as the accumulation of water-soluble salts in the soil to a level that impacts agricultural production, environmental health, and economic welfare (FAO, 2011). There are four ways in which salinization can happen, irrigation, aerosol, floods and seepage (See Figure 16). Especially in the context of agriculture these all have significant consequences. Salinization causes soil degradation that causes plants to be unable to grow. This means that there is significantly less yield of crops (M.S). But also, other vital functions in society are at play. For example, the availability of drinking water. When salinization reaches drinking water production facilities, these will have to incur costs for desalinization or sourcing water elsewhere (M.S). This has its effects on the prices of potable water in Bangladesh (Talha, 2021). When desalinization is not an option, however, in poorer areas, for example, people will have to rely on salter/brackish water for their daily hydration. This can cause substantial health effects, such as shown experienced also in Bangladesh (Das et al., 2019) (S.S). One of the last resorts that are associated with salinization, and other consequences of sea level rise is emigration from agriculture-intensive regions. Soil salinity is found to have large and significant effects on migration in Bangladesh (J. Chen & Mueller, 2018) (HC.S, etc.). Lastly, besides agriculture and drinking water, also energy production and industry might incur extra costs for desalinization (van Kleef & Laro, 2008) (M.S, J.S, EC.S).

In this section, the focus is thus on the main effects of salinization; on agriculture, on drinking water and industry. First, their direct effects are analysed, and next their indirect effects. According to Tzemi et al. (2021) studies on economic costs of salinization due to climate change are limited. Exceptions are the studies of Richards & Nicholls (2009) and Bosello et al. (2011) which address all key biophysical impacts of sea-level rise and focusing on salinization, the results show costs are substantial and increase with sea-level rise. However, these do not seem to do this on a detailed scale. In the view of Tzemi et al. (2021), this is partly because of the unavailability of data on the extent and severity of salinization. This hinders biophysical modelling of impacts of salinization which is a prerequisite to any assessment of the economic impacts.

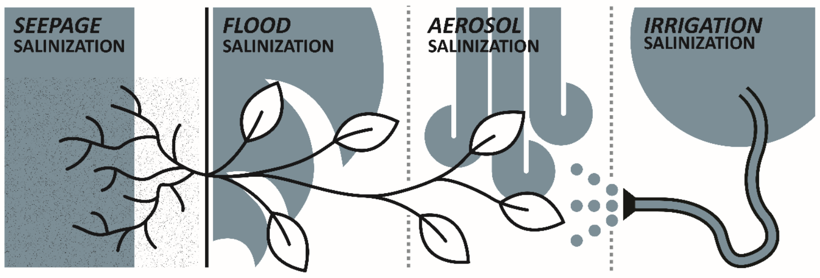


Figure 16; Four types of salinization processes (de Waegemaker, 2019)

Agriculture

The direct effect of salinization on agriculture in an area can be measured in a decrease in crop yields. In Ruto, et al. (2021) the economic impacts of salinity induced soil degradation is analysed. In the North Sea region, three of the four types of salinization processes take place. Irrigation salinization, flood salinization and seepage salinization. In a scenario analysis, the risk of salinization is dependent on the salinity of the irrigation water, floodwater and the salinity of the groundwater respectively (See Table 3).

Table 3; Salinity scenarios employed in economic analysis (Ruto et al., 2021)

Salinization process	**Description**	**Salinity scenario levels (EC ds/m)**
Irrigation salinization (IS)	Salinization that results from irrigation of non-saline agricultural soils with salt or brackish water.	4, 8, 12, 16
Seepage salinization (SS)	Salinization that results from the rise of salt rich groundwater. The salt rich groundwater may be hydrologically linked to nearby seawater.	0.02, 0.09, 0.2, 0.7 (or 6, 26, 64 and 215 mg/l Chloride)
Flood salinization (FS)	Salinization that occurs as soils are flooded by brackish or salt-rich water. Flood risk may be exacerbated by climate change	7.1, 6.08, 5.06, 4.04, 3.03 (dS/m)

In Ruto, et al. (2021) financial losses incurred by salinization for individual farms are extrapolated into countries and regions. The results then show there is a significant economic impact of salinization in the North Sea region. The magnitude of the economic impact of salinization depends on various factors including which type of salinization, the salinity, the types and market prices of crops that are grown. This recent study shows that salinization risk modelling is still at an early stage, where only assumptions on irrigation, flooding and seepage are used. In their next chapter, however, progress is made on the mapping of salinization intensity and risks (Tzemi et al., 2020). ‘The extend of salinization processes were explored for each of the countries surrounding the North Sea by looking at any established maps of salinization and salinity risks. Our findings show that the potential threat of salinization across the North Sea is very diverse, with the risks varying considerably between countries. We found an overall lack of data, both of water monitoring and soil sampling, on salinity in the region. This is not surprising, given that salinization is historically of limited extent in the region. However, in the face of future climate projections we anticipate salinization to have much greater impact on the region. In order for agricultural systems in the region to adapt, more extensive mapping and monitoring of salinization needs to be conducted' (Tzemi et al., 2020). This means that salinity mapping still can only be based on assumptions. From the increase in salinization due to sea level rise and the costs that are incurred for desalinization or loss in yields, further effects can be identified as well. In the stylized framework from Ruto et al. (2021) the wider impact of salinization increases are visualized (See Figure 17).

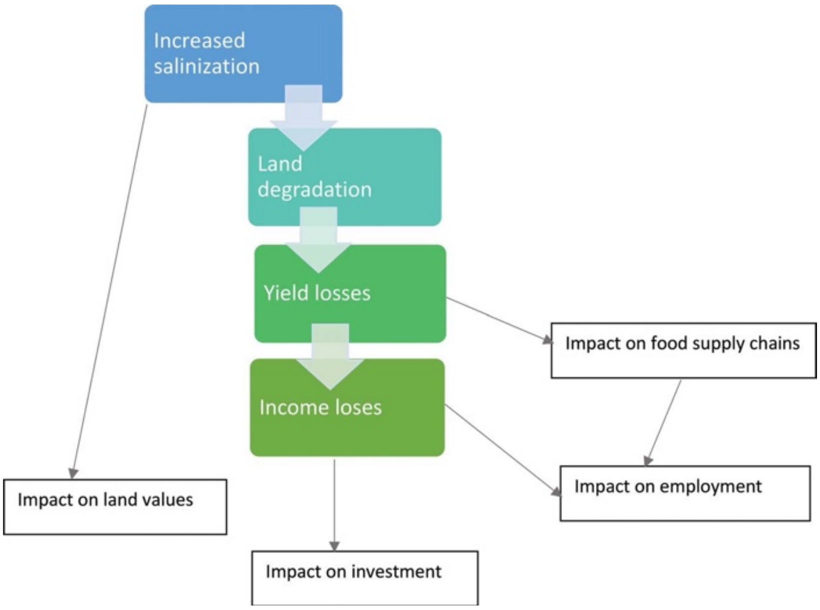


Figure 17; Stylized framework for assessing farm scale and wider impact of salinization (Ruto et al., 2021)

In their framework, they argue that increased salinization due to SLR causes land degradation (NC.S), which in turn causes losses in agricultural yield and income losses (M.S), which causes impacts on food supply and employment and investment respectively (J.S, EC.S). The relationship between salinization and agricultural yield losses is relatively well documented. For example, already in 1995, Ghassemi et al. found that, worldwide, yield losses due to salinity account for up to about $12 billion per year. Outside of yield losses, higher-order effects have not been assessed in great detail. Richards and Nicholls (2009) and Bosello et al. (2011) do account for salinization in their DIVA model that estimates economic impacts of sea level rise but do not distinguish between the different ways and severity salinization can impact the economy. Also, no adaptation to salinity intrusion is included within the DIVA model, which in practice would make large differences, as adaptation to salinization is possible with, for example, saline agriculture. This is due to their DIVA model being unable to account for the high level of complexity in how and which salinization can occur, and what is vulnerable to it (Ruto et al., 2021) (S.S, M.S, J.S, EC.S, NC.S, HC.S). On the relationships in the stylized framework of Ruto et al. (2021), not much empirical evidence has yet been given. However, on each relationship, some effects on case level and hypothetical levels have been identified.

Firstly, the impact of salinization on land prices. Von Braun et al. (2013) especially see an increase in land prices due to land degradation. This of course does not mean that the salinized grounds are priced at a higher level, but that the remaining lands that are suited for agriculture become increasingly expensive (M.S, EC.S). The interaction of growing food and resources demand, together with the inelastic supply of land causes worldwide price surges. This mechanism can be explained; the rise in demand for agricultural products raises their prices. In turn, the increase in returns from land assets drives land prices. The inelastic nature of total land supply, combined with the rising degradation of agricultural areas, makes land resources increasingly more scarce, amplifying this process. On the backside, however, the loss in production yields from land assets that are salinized makes for a lower price. However, in the case of less agricultural yields, it may result in changes in land-use plans from agricultural to urban or natural. These both have different implications for land prices, as nature has a very low value and housing plots yield a lot. The opportunity costs of agriculture are thus the price loss, but can thus also be a price gain when a plot suddenly becomes viable for housing (H.S, M.S, EC.S).

Second, the impact of yield losses on the functioning of food supply, and its higher-order effects, such as on employment. In this context, not many estimates of the causal effect salinization have on food security have been made. But signs are shown that salinization can have an impact on food security in for example the dry seasons in Myanmar (Oo et al., 2017). While Myanmar produces enough food to meet domestic needs and is a food exporter, abundant food supplies for the poorer groups who live in the dry zone and salinized areas can still be scarce, mainly due to drought and salinity. To survive, alternatives to the food had to be found, low paying jobs for a wage had to be found or even foraging was applied (M.S, J.S. Another coping strategy was seasonal labour migration, which made remittances to the home villages possible (HC.S, M.S). Food insecurity is also identified to be a driver of migration by Sadiddin et al. (2019). Furthermore, food insecurity can even lead to poverty traps, when hunger is so severe that working for a wage is not possible anymore (Dasgupta, 1997) (HC.S, M.S). In more developed countries, that do not rely on agriculture, these effects will probably not take place, but worldwide, also in developed countries, the quest for freshwater irrigation in agriculture will likely increase crop prices (M.S). An example of this is Chen et al. (2011) in which sea level rise and salinization effects reduce worldwide rice outputs by 2%, which is estimated to increase rice price levels by 10%.

Lastly, the impact of income losses due to salinization on employment and investment. The decrease of income from agriculture in salinized areas makes for a shift of investments from agriculture in these areas, into other areas (EC.S). Another possibility would be that investments will increasingly go to other land uses, such as a building. Either way, investment in agriculture might shrink, but this does not mean the halt of investment in other sectors that are less salinization sensitive. For employment, this means that the manpower needed for agriculture will decrease. Farmers that cannot offer high wages to their workers will mean the abandoning of the agriculture sector and a decrease in employment (J.S). However, when the right alternative is found, investment in new sectors in the area might give a rise to other jobs, especially when these sectors are more labour intensive than agriculture. Examples of these alternatives could be the adoption of saline farming (Cheeseman, 2016; Negacz & Vellinga, 2021).

Drinking water

On the impacts of salinity in drinking water much has been written, but merely in the context of Bangladesh, to the author's knowledge the only country suffering from salinization contaminated drinking water currently. The primary effect of salinity reaching drinking water sources is the process of getting it out, desalinization. Using conventional energy sources, seawater desalination costs range from 0.4€/m3 to more than 3€/m3, whereas brackish water desalination costs are roughly half that. Using renewable energy sources is substantially greater, and in some situations can even reach 15€/m3 (Karagiannis & Soldatos, 2008). When considering the water use of people in the area, to remain their level of water consumption this cost can rise to millions or even billions (M.S). A quick calculation for the city of Groningen; about 200,000 inhabitants and Dutch people use on average 1m3 per week or about 50m3 per year. The water used for personal households only in Groningen is thus 10 million m3. This accounts for a minimum of 2 million per year for brackish water. Keeping the saltwater out is much cheaper, by using innovative techniques in sea-locks and other coastal barriers, the Netherlands try to keep salt intrusion at a minimum (see STOWA, n.d.).

Indirect effects of salinization on drinking water production are health effects. Valuing water, which is of importance in assessing the beforementioned effects of salinization in society, has seen an increase in interest in the past year. In a report by UNESCO (2021), the practices of valuing water have been summarized. The value of clean water to society is very high. Considering the health effects of consuming salinized or dirty drinking water the cost-benefit ratio of investment in clean water is about 1 to 2 (WHO, 2012). These benefits come from health, health economic (saving hospital costs), and time value of sourcing water elsewhere (S.S, M.S, EC.S). But these do not even include the benefits that happen due to education, in the case of school absence due to diarrhoea from dirty drinking water, which is a leading cause of malnutrition in children under five years old (WHO, 2017) (HC.S). Cleaner drinking water can thus also be an economical decision. In Rygaard et al. (2011) an economic optimum of improving drinking water with the use of membrane desalination and remineralization is calculated. A further range of impacts on public health, material lifetimes and consumption of soap are also applied in their practice.

Industry

However, personal households are not the only users of fresh water in the Netherlands and around the world. Water uses of industry and electricity plants are much higher (see Figure 18). Industry, after agriculture, is the second-largest beneficiary of fresh-water resources worldwide. The direct effect of salinity in the water used for the industry is not assessed on a high level, but signs exist that in the future industry might have to adapt to salinization with the use of saline water for cooling, for example, which has seen an increase in share in the Netherlands (Environmental Data Compendium, 2020). This incurs costs, as lower salinization in the water is less costly to produce energy with (Harto et al., 2014) (M.S).

Water risks in the industry can cause significant costs, which makes a country also less interesting to invest in (M.S., EC.S, J.S). An example is when companies were urged to reduce their water use in drought and thus had to discontinue production (Parool, 2013). But there are more indirect consequences that companies that use water as an input for their operations have to take into account. According to UNESCO (2021), the financial performance in the Energy, Industry and Business sectors can be affected by water in various ways (see Figure 19). However, monetizing water is a difficult task. Most companies do not pay the real price for water that they use for production. For example, by quantifying hidden costs, Colgate Palmolive discovered that their true cost of water was 2.5 times what they paid for it (UNESCO, 2021). But still, a decrease in water availability can yield very different economic outcomes. A way to monetize water can thus be by ascribing GDP to a metric ton of water use. In Canada for example, 'industrial water use intensity was 18.3 cubic meters per $1,000 of real GDP' (Statistics Canada, 2018). A decrease in the quantity of freshwater usable for the industry then yields a decrease in GDP.

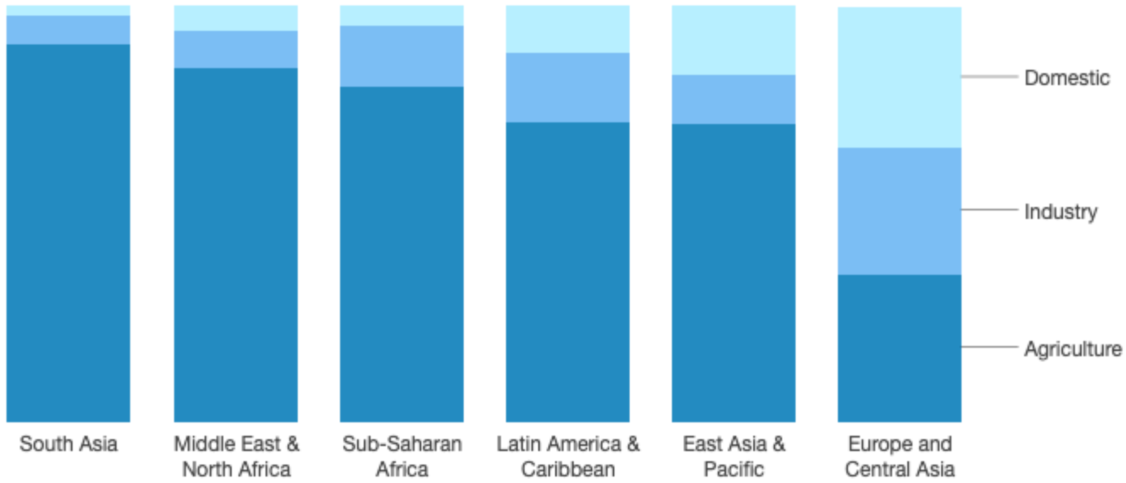


Figure 18; Share of freshwater withdrawals by sector (%) in 2014 (World Bank, 2017)

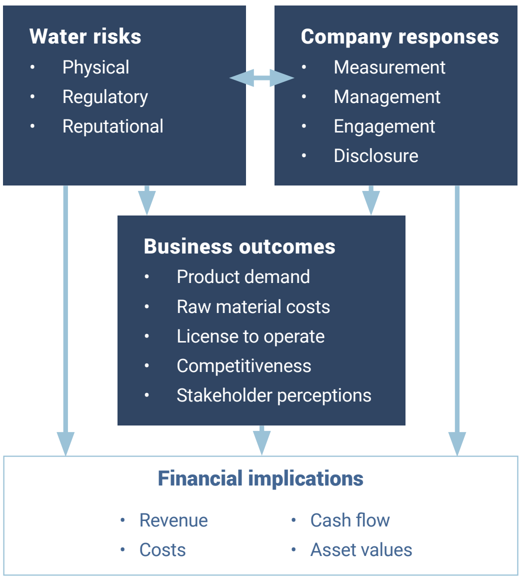
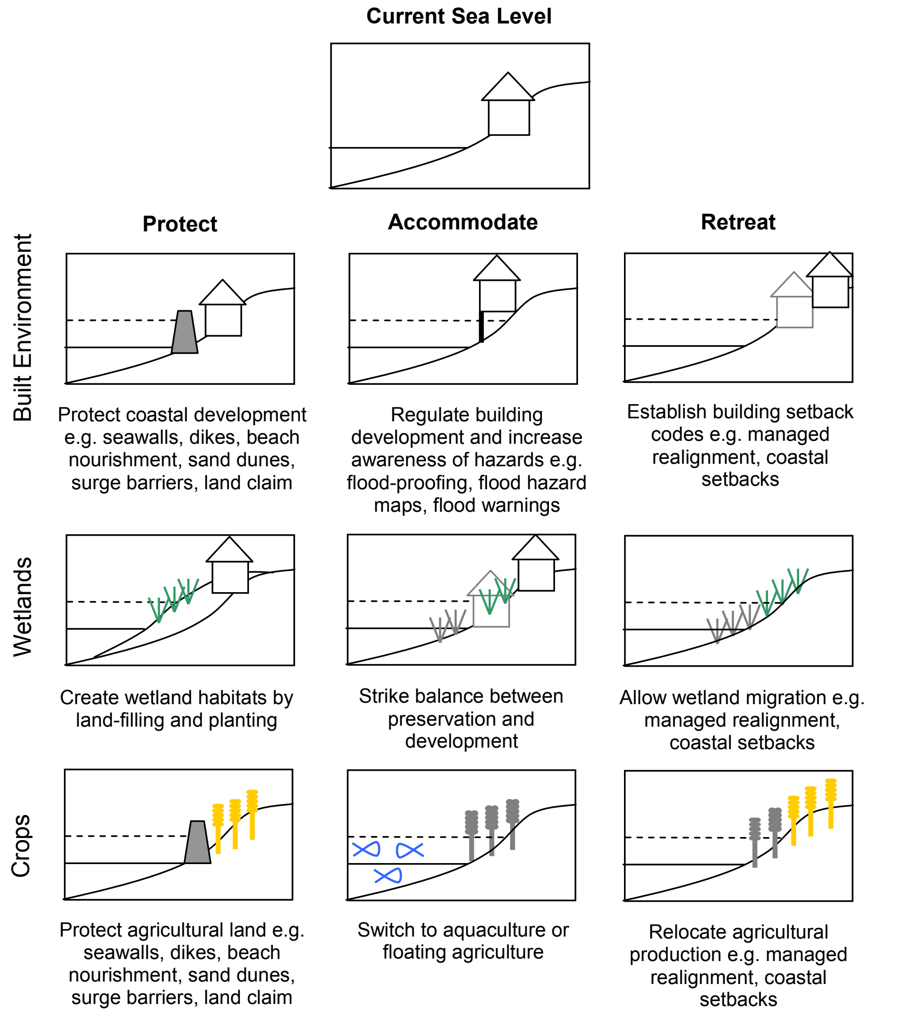


Figure 19; Water risk and financial consequences in the Energy, Industry & Business (EIB) sector (UNESCO, 2021)

2.3 Adaptation

Adaptation to sea level rise can be defined as the equipment, techniques, practical knowledge, skills or institutional instruments required to reduce its impacts (Linham & Nicholls, 2010). Adaptation is described as one of the fundamental effects of SLR because it is people's primary response, as seen in Tol et al. (2008)'s illustration, and it has unique implications on broader welfare dimensions that cannot be assigned to one of the biogeophysical effects on the X-axis of the cube in Figure 3. For adaptation to sea level rise, three strategies can be defined, first suggested by IPCC CZMS (1990) and shown in Figure 20:

1. Protect: defend vulnerable areas, especially population centres, economic activities and natural resources.
2. Accommodate: continue to occupy vulnerable areas but accept the greater degree of flooding by changing land use, construction methods and/or improving preparedness.
3. (Planned) retreat: abandon structures in currently developed areas, resettle inhabitants and require that new development be set back from the shore, as appropriate.



The dashed line represents future SLR. Grey houses and vegetation indicate their previous locations prior to relocation or natural migration

Figure 20; Protect, accommodate & retreat responses to SLR (Linham & Nicholls, 2010)

In the Dutch literature, several comparable strategies are identified, with a further level of detail, that provides us insight into what is at stake in Dutch water management considering sea level rise. In the Haasnoot, Diermanse et al. (2019) for the Netherlands, they propose Protect-open (Beschermen open), Protect-closed (Beschermen gesloten), Accommodate (Zeewaarts) and Retreat (Meebewegen) (see Figure 22). In current research the international standard is used, with Protect-closed serving as the Protect strategy, and Retreat.

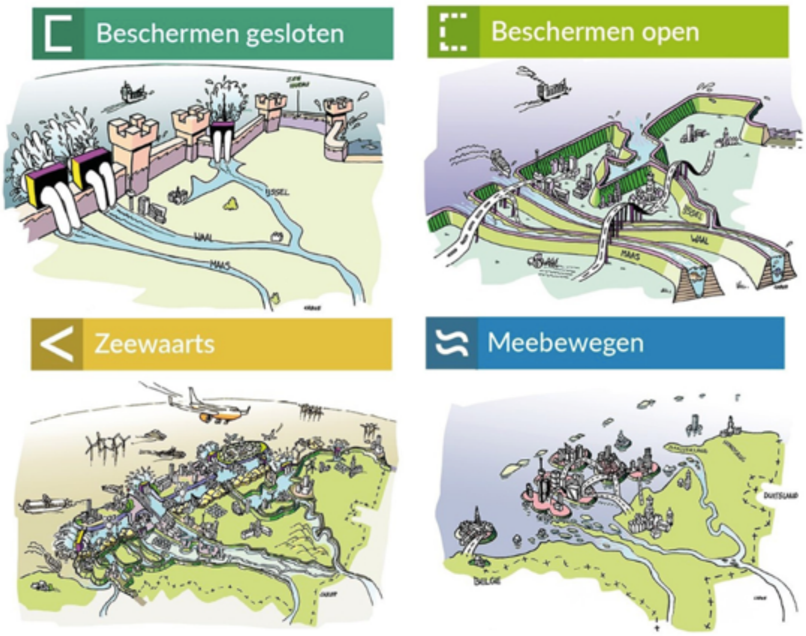


Figure 21; Solutions for adaptation to high sea level rise in the Dutch delta (Haasnoot, Diermanse et al. 2018)

2.3.1 Protect

There are many effects and barriers that can be identified when using the strategy Protect. The physical effects of building a dam for example can lead to the lock-in of fish migration and blocks river navigation (E.A.P, NC.A.P, EC.A.P). But, maybe more importantly, the costs of building the protection against flooding can be significant (M.A.P, EC.A.P). These costs typically consist of construction costs and expenses for operation and maintenance. Aerts (2018) provides these costs to use in cost-benefit analyses. The positive effects of protection often outweigh the costs of protection in developed countries (Anthoff et al., 2010). But for example, scarcity of resources (Hinkel et al., 2018) and economic decline (Anthoff et al., 2010) make Protect less attractive.

There are two reasons that often money is tight (EC.A). 1. Benefits occur over a long time horizon, 2. Benefits are distributed across stakeholders. However, there are ways to counter this. For example, by the creation of short-term revenue streams by developing real estate in newly created land or making areas more directly more valuable through enhancement (M.A, EC.A). An example of this is Hulhumalé in the Maldives (Hinkel et al., 2018) or Singapore, in which the Marina Barrage functions as flood protection, while many other uses have been found after its development to serve as an economic centre as well (Detter & Fölster, 2017) (E.A.P, M.A.P, J.A.P, H.A.P, EC.A.P).

Also, Protect becomes less attractive in areas with decline of the coastal population is assumed. Anthoff et al. (2010) recognize that in their model, future economic growth is estimated quite optimistically: lower growth may lead to less prevented damages in monetary terms (M.D.P), but it will also reduce the capacity to protect (EC.D.P). Also, they note that a cycle of decline in some coastal areas is not inconceivable, especially in future worlds where capital is highly mobile and collective action is weaker.

However, there are also effects of Protect that may serve as economic stimulus. As Husby et al. (2014) put forward, flood protection can also serve other purposes. In the Delta works several constructions also were beneficial to fresh-water supply, transport infrastructures such as roads and new land (E.A.P, S.A.P, M.A.P). Furthermore, Bosello et al. (2011) mention further second-order effects. 'While forced investment in coastal protection is bad for the overall economy, it also provides a stimulus for the construction sector. As coastal protection is localized, this effect would stimulate local and regional economies. This means that the investment and competitiveness gains of coastal protection by Dutch construction companies must also be taken into account (M.A.P, EC.A.P).

However, this is a typical moral hazard problem. People have moved to newly protected regions as a result of the creation of new land (J.A.P, H.A.P, HC.A.P) (Husby et al., 2014). And thus risk of moral hazard exists, when people increasingly move to flood-prone areas, instead of moving away from them. This can be called the 'safe development paradox', which according to the results from Haer et al. (2020) can make protection measures increase the impact of a flood (S.A.P, M.A.P, EC.A.P, HC.A.P). They instead believe that steering households into implementing building-level measures, by for example a discount on an insurance policy, would decrease the impacts of flooding disasters.

Protect has other limitations, such as protection against salinization, which is typically only prevented by the natural process of flushing with freshwater, which Protect cannot guarantee (Haasnoot, Diermanse, et al., 2019). But also societal limits, a lack of capacity of governance structures to plan, implement, enforce, monitor and maintain the Protect measures, which can lead to government distrust. In the Netherlands, recently this has not been a problem, as we've had a long history in water management. However, there is also a side to that. With policymakers and regulators often involved in coastal protection companies, regulatory capture may occur in the industry. This leads to a larger emphasis on the protection side of adaptation and less on retreat (Dal Bo, 2006) (I.A.P).

2.3.2 Retreat

Retreat or Managed retreat, is 'the application of coastal zone management and mitigation tools designed to move existing and planned development out of the path of eroding coastlines and coastal hazards' (Neal et al., 2005). In contrast to the Accommodate option, there will be no endeavours to be able to remain in the same places, and the functions must give way. There are several responses to consider in this fashion. Due to flooding, for example, wetlands can start to exist. An example of this is the 'drunken land of Saeftinge' in Belgium, which once was a polder with villages, but now houses a vibrant ecosystem for birds (Het Zeeuwse Landschap, 2013) (E.A.R, NC.A.R).

The recent experiences with managed retreat are analysed in Hino et al. (2017). They show that for different causes of retreat and different levels of voluntary retreat, different responses of society and different levels of remuneration are necessary (M.A.R, EC.A.R). However, they have been proved to be cost-effective; Rose et al. (2007) found that the benefit of retreat remuneration were 2-5 times the costs of the remuneration.

2.3.3 Accommodate

Accommodating flood risk is also a possibility. Increasing the flexibility of infrastructure towards floods, using floods as a source of water and nutrients for agriculture, or building houses on poles all belong to the possibilities for accommodating floods into our lives. The Accommodate option does not allow certain land uses to be continued. For example, it may be feasible to build houses on poles, but agriculture that does not allow salinity will likely be less effective. This means that certain functions need to be re-evaluated.

Accommodating thus will bring sacrifices, but also boost innovation and redistribution of investment potential. Accommodating flooding in urban areas is deemed expensive. Most buildings do not allow for flooding, and erosion will damage the fundaments on which the buildings are designed. Accommodating flooding in areas that aren't fully built, might be a less expensive practice. Flood damages are much lower for floodplains than for a densely built city. Accommodating the effects of sea level rise exists of different measures for each of the physical impacts. For example, when accommodating to flooding, cities will be built on higher grounds or buildings in lower zones will be adapted in a way that they are not damaged by floods. For salinization, for example, desalinization could be an example of accommodating, but also the use of halophytes in agriculture, which are plants that grow in salt grounds. For coastal erosion, instead of coastal supplements, the inwards shifting coastline will be made into wetlands, where people and wildlife can continue to live.

The current study's scope excludes Accommodate from its analysis. Accommodate is still a strategy that is hard to concretize, and it is a hybrid of the two extremes, Protect and Retreat. Accommodate will be left out in favour of simplicity in the next chapters and clarity in the concretization of adaptation measures implemented. That means that coastlines are either protected or, if this is not done, they will eventually have to be abandoned and will be lost to the rising sea, as is assumed before in Fankhauser (1995).

3. Conceptual model

The effects of SLR are summarized in Table 26. From the table, it can be obtained that there are many more effects in play and that thus an analysis only considering the narrow welfare effects miss a major share of effects. To illustrate, a previous study on the effects of SLR in the RMDS region, Koks et al. (2014), only takes into account the effects of flood damages on labour and capital and indirectly production losses and GDP (see Figure 5), practically only the first column on the left of Table 4.

Table 4; Identified effects of SLR and Adaptation

Damages	Count in # Strategies	Migration	Count in # Strategies	Salinization	Count in # Strategies	Adaptation	Count in # Strategies
H.D	3	M.M	3	M.S	3	M.A.P	1
E.D	3	J.M	3	S.S	3	EC.A.P	1
S.D	3	EC.M	3	HC.S	3	E.A.P	1
EC.D	3	HC.M	3	J.S	3	NC.A.P	1
M.D	3	H.M	3	EC.S	3	J.A.P	1
NC.D	3	I.M	3	NC.S	3	H.A.P	1
J.D	3	S.M	3			S.A.P	1
						HC.A.P	1
						E.A.R	1
						NC.A.R	1
						M.A.R	1
21		21		18		11	SUM = 71

A first step toward obtaining empirical evidence to support decisions on adaptation measures against sea level rise is to conceptualize all of the effects of sea level rise. Conceptual (mental) models capture our current understanding of the structure and workings of a system (Gupta et al., 2012). The findings that are provided by the previous chapter are confined to a model, which can be seen in Figure 23. The base of the conceptual model is the effects that were found in the previous parts. These effects were cast into a categorization of broader welfare dimensions. Not all the dimensions of broader welfare are used. In Chapter 4 the motivation for this is given. The effects are structured in a way that allows the reader to use the 'cube' of Figure 3 to comprehend the multitude of effects identified. As previously mentioned, the adaptation option of Accommodate is not considered, as this is a hybrid of the two extremes Protect and Retreat. In the conceptual model, as the multitude of effects does not allow for each direct effect to have an individual broader welfare dimension effect, it uses a multitudinal arrow. For example, economic stimulus caused by the investment in protection measures has effects on Material welfare, Jobs and Economic capital. Singular effects, often feedback effects, are shown with singular, narrower arrows, for example, the increase of salinization due to flooding.

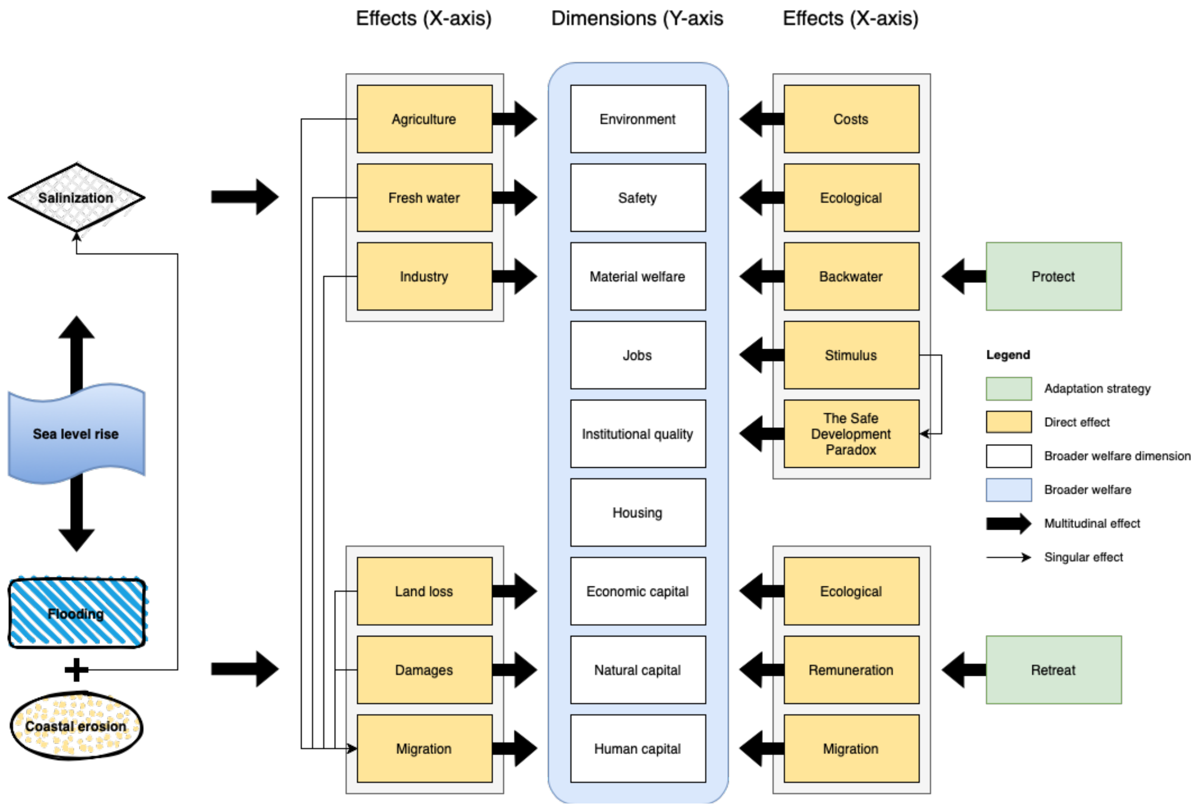


Figure 22; Conceptual model of SLR effects on broader welfare

4. Methodology

For the analysis to determine the preferable strategy of adaptation in the Netherlands a Multi Criteria Analysis (MCA) is used, which is a structured approach to determine a preferred option among alternatives (Department for Communities and Local Government, 2009). The options can achieve several criteria. These criteria in this case are the indicators of broader welfare, which will be identified in the following chapter. The impact of the effects of SLR on welfare dimensions in different adaptation strategies can be based on monetary values and qualitative impact categories and criteria. This way, the impact of sea level rise on for example Environment can be included in the analysis, alongside monetary effects on GDP. This allows for the inclusion of all the impacts, direct or indirect, on broader welfare. The use of an MCA requires some steps: 1) Identifying objectives of the MCA. 2) Identifying options for achieving the objectives of the MCA. 3) Identifying the criteria and weights to be used to compare the options. 4) Analysis of the options.

The first two steps are already implicitly covered by the previous chapters. The third step, identifying the criteria on which a comparison between the options of adaptation is made, needs to be accomplished. In a MCA, the criteria on which a certain policy is assessed must first be identified. As mentioned earlier, this thesis aims to provide a broader economic evaluation of the concepts of sea level rise and adaptation in the Netherlands. For a broader economic analysis, the use of GDP as a criterium is not enough. As put forward by the OECD (2004), GDP 'measures income, but not equality, it measures growth, but not destruction, and it ignores values like social cohesion and the environment. Yet, governments, businesses and probably most people swear by it'.

According to ESB (2019), there is a growing consensus that measuring the broader economic impacts are best measured in a more explanatory conceptual set of indicators instead of an aggregated index. For the Netherlands, this practice has been performed in the Dutch monitor of broader welfare (CBS, 2020b; CBS, 2021a). This yearly report not only presents the level of broader economic welfare in the Netherlands in 2021 but also whether the actions to reach this level of welfare puts a strain on future generations. In addition, the monitor analyses the level of distribution of this welfare over different population groups. As previously mentioned, the effects of sea level rise have very different implications concerning the living environment, future generations and other broader welfare dimensions. Therefore, it could be argued that this is in line with the data used in the Dutch monitor of broader welfare. Thus, for the assessment of economic results of different adaptation methods, the assessment criteria of this monitor of broader welfare are used.

Rijpma et al. (2017), however, managed to still turn the conceptual set of indicators into one integral index: the Broader Welfare Indicator (BWI). This way trade-offs between different dimensions become explicit and as such, the debate between trade-offs becomes more disciplined. Working with a single indicator also enables for cross-regional comparisons (ESB, 2019). Because the current study will look at two regions, one indicator will be employed. Although the effects on future generations' welfare are ignored in Rijpma et al. (2017)'s BWI, they will be incorporated in the current study, allowing for estimates of SLR effects in alternative adaption options for future generations, which is critical given the nature of sea level rise.

The Dutch monitor of broader welfare is divided into 12 categories, 8 for 'Here and now' and 4 for 'In the future'. These total more than 40 indicators, of which some are chosen and divided among the 11 BWI categories to allow for the use of Rijpma et al. (2017)'s weights, as shown in Table 5. As a result, the current study combines the dimensions of the Dutch monitor of broader welfare with the BWI weights. In the BWI weights, it was decided to use the information the appreciation that Dutch people attach to the different dimensions within the OECD Better Life Index (OECD, 2021). Therefore, the weighting of dimensions is not subjective but derived from the opinions of the Dutch responders in the OECD Better Life Index. To these dimensions, the dimension of future generations is added, as these are provided by the regional monitor of broader welfare (CBS, 2020b). These will be given weights of 0.855, as this is the average value of the weights provided. A comparison between the indicators from Rijpma et al. (2017) and the CBS regional monitor of broader welfare (2020) is given in Table 6, to show there is not much difference between the measurement of these dimensions.

In determining the effect of sea level rise on broader welfare, the dimensions of the Dutch monitor of broader welfare Environment, Safety, Material welfare, Jobs, Institutional quality and Housing were the six dimensions that were touched upon the most during the discussion of effects of SLR and adaptation. The other dimensions however are more difficult to be assigned an impact. These are Subjective well-being, Health, Education, Social relations and Work-life Balance. The effects on these dimensions depend more on regulatory and subjective indicators and less on the spatial and income economic implications of SLR and its adaptation options. Therefore, in this section, only the dimensions that are affected will be assigned values to use in the multi criteria analysis to determine the preferred adaptation option in the RMDS region.

The scores of the different scenarios in a certain dimension will be discussed in the case studies and are determined by various methods that are suitable for each dimension. Once every strategy in each dimension is scored, the scores within each dimension are multiplied with the dimensions' weight to obtain the weighted score. To obtain the final score of the Strategy in the MCA, the weighted scores of each Dimension will be summed up for a Strategy. An exemplary calculation of the MCA is shown in Table 7. The output scores, in the 'Score' row, themselves don't serve an interpretation but purely provide a score that can be compared between the different strategies. For example, in the exemplary calculation, the status quo has the highest value, after this Protect and Retreat respectively. This, in the case of broader welfare analysis, would mean that the status quo offers the highest welfare, and Protect is the preferable strategy of adaptation based on the MCA's parameters. Note that when the weights are adjusted, the results can change, for example, if there is variability in preferences for dimensions of broader welfare. If for example, not the preferences of Dutch people from the OECD Better Life Index (Rijpma et al., 2017) are used, but equal weights are used, no preference between the Retreat and Protect can be obtained (see Table 7, 'Score equal weights' row).

Table 5; Exemplary calculation of MCA scores

Dimension	Status quo	Weigthed score	SLR	Weigthed score	Retreat	Weigthed score	Protect	Weigthed score	Weights	Equal weigths
Environment	1.0	0.9	0.5	0.5	0.5	0.5	1.0	0.9	0.92	1.0
Safety	1.0	0.9	0.0	0.0	1.0	0.9	1.0	0.9	0.92	1.0
Economic capital	0.5	0.4	0.0	0.0	1.0	0.9	0.5	0.4	0.86	1.0
Score		**2.3**		**0.5**		**2.2**		**2.3**		
Score equal weigths		**2.5**		**0.5**		**2.5**		**2.5**		

Table 6; Weights of the different dimensions of broader welfare (Rijpma et al. 2017)

Dimension	BWI Weight
Subjective wellbeing	1.13
Health	1.03
Education	0.96
Housing	0.91
Environment	0.91
Safety	0.91
Material welfare	0.85
Jobs	0.83
Social relations	0.78
Institutional quality	0.67
Work-life Balance	0.96

Table 7; Comparison Rijpma et al. (2017) and CBS (2020b) indicators of Broader Welfare

Dimensions Rijpma et al. (2017)	**Weight in Rijpma et al. (2017)**	**Variables**	**Dimension CBS (2020b)**	**Weights used**	**Variables**
Subjective wellbeing	1.13	Happiness Life satisfaction	Wellbeing	1.13	Life satisfaction Leisure satisfaction
Health	1.03	Life expectancy	Health	1.03	Obesity Life expectancy Experienced health Persons with prolonged illnesses
Work-Life Balance	0.96	Hours worked	Labour and Leisure	0.96	Satisfaction with travel time to and from work
Education	0.96	Educational attainment PISA Score Average years of education	Labour and Leisure	0.96	Highly educated population
Housing	0.91	Housing satisfaction	Housing	0.91	Satisfaction with living environment Satisfaction with home Distance to amenities
Environment	0.91	Particulate matter emissions Living Planet Index	Environment	0.91	Nature area per capita Nature and forest area Emissions Water quality
Safety	0.91	Violent crime rate Homicide rate	Safety	0.91	Delicts Crimes
Income	0.85	Disposable household income	Material welfare	0.85	Median disposible income GDP
Jobs	0.83	Short-term Long-term Flexible	Labour and Leisure	0.83	Labor participation Unemployment Vacancy rate
Social relations	0.78	Social contact	Social	0.78	Social contact
Institutional quality	0.67	Voice and accountability Political stability	Society	0.67	Trust in institutions Trust in others

		Government effectiveness Regulatory quality Rule of law Control of corruption			Social work
-			Economic capital	0.855	Average debt per household Median wealth per household
			Natural capital	0.855	Private solar energy Nature and forest area Built area Particulate matter emissions Phospate emissions in agriculture Nitrogen emissions in agriculture
			Human capital	0.855	Worked hours per week Highly educated people Life expectancy Experienced health
			Social capital	0.855	Social cohesion

5. Case studies

In this case study, an analysis will be conducted for two locations in the Netherlands, using effects gathered from the literature that were structured by the SLR cube and visualized in the conceptual model. In paragraph 5.1 the first region will be introduced. In paragraph 5.1.1 the specific measures of adaptation and their consequences will be delineated. After that in 5.1.2, the choices for the scores of the multiple criteria are explained. In 5.1.4 the results of the MCA will be discussed. This order is repeated in 5.2 for the second region.

In 5.1.2, the consequences are structured based on the Y-axis of the cube of SLR, in Figure 3. Within the Dimensions, on the Y-axis the different choices of Strategy on the Z-axis will be discussed. The effects that have an impact on the Dimension for each Strategy are not structured in any predefined order. This is due to the fact that in practice, the effects observed in a specific region, are sometimes unable to be attributed to just one of the effects used on the cube's X-axis. For example, the environment may suffer impacts from both flood damages and salinization. Therefore in this section, it is chosen to not use a further categorization from the cube’s X-axis. This means that first, the Dimension Environment will be discussed and within this Dimension, the three strategies are discussed and within the Strategies, the effects will be discussed (see Figure 23).

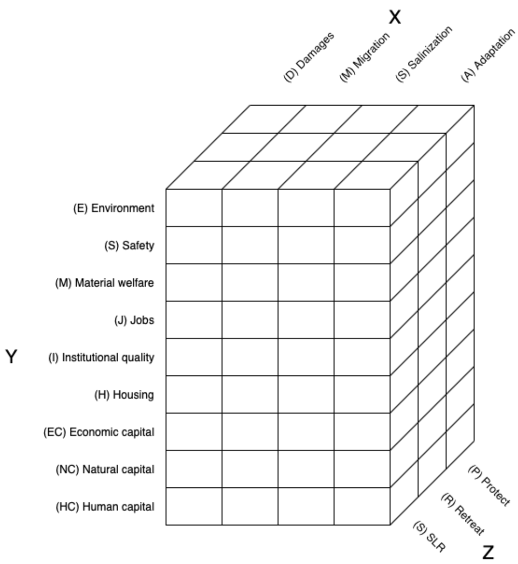


Figure 23; Y-axis and Z-axis in the cube of SLR

5.1 Rijnmond-Drechtsteden

The Rijnmond-Drechtsteden region, further referred to as RMDS, is the first case. This densely populated region includes two major cities, Rotterdam and Dordrecht, and is located in the Randstad region of the Netherlands. It consists of the municipalities of Alblasserdam, Albrandswaard, Barendrecht, Brielle, Capelle aan den IJssel, Dordrecht, Goeree-Overflakkee, Hardinxveld-Giessendam, Hellevoetsluis, Hendrik-Ido-Ambacht, Krimpen aan den IJssel, Lansingerland, Maassluis, Nissewaard, Papendrecht, Ridderkerk, Rotterdam, Schiedam, Sliedrecht, Vlaardingen, Westvoorne, Zwijndrecht. The region of Rotterdam houses the logistical centre of Europe and thus could suffer significantly from closed barriers to the North Sea. Furthermore, the petrochemical industry that is situated in the port and an agricultural centre called the Greenport Westland are threatened when inundated. But besides that, also a wealth of wild nature in the Biesbosch is situated in the region.

For the RMDS region, a specific delta program is made (Deltaprogramma Rijnmond-Drechtsteden, 2020), in which a map shows which areas are inundated fast and deeply during floods. This means that the valued assets that are in these areas are more vulnerable to flooding. These areas are indicated as dotted in Figure 24.

Figure 24; Inundation map RMDS (adapted from Deltaprogramma Rijnmond-Drechtsteden, 2020)

As can be seen from the map, parts of the built-up centre of Rotterdam will likely be inundated, but also large parts of the polders south of Gouda, and north of Dordrecht including Dordrecht itself. Furthermore, what is not indicated in the map, a loss of ecosystem services, the welfare humans obtain from having a healthy environment, can be expected from extensive sea level rise in the Biesbosch area directly south of Dordrecht.

As the occurrence of salinization is not readily mapped for this region, this paper cannot show which areas suffer most from salinization. Therefore, an assumption needs to be made to what extend salinization will damage the region. The inland areas will suffer from substantial salinization as the fresh river waters cannot flush out the intruding water from the sea. The rivers offer a way to let saltwater get to the more inland areas. Eventually, this will reach a level where the whole area might suffer from salinization.

The effects of coastal erosion in the area occur only at the direct coastline at the Maasvlakte, which is part of the port area of Rotterdam. At the Maasvlakte, likely coastal erosion does take place, but to date, this has been no problem due to sedimentation (El Hamdi, 2013). As indicated by the Port of Rotterdam (2019) itself the main damages occurring due to sea level rise are direct damages to 'buildings, systems and other facilities', and 'indirect damage resulting from business operations being shut down and/or the infrastructure present not being optimally available for use. The risk of environmental damage is limited, and casualties are neglectable'. For the region of Rotterdam, Koks et al. (2014) estimate these direct and indirect economic effects of SLR, and hence also on the Port.

What is equally important for the Port's area is the effect of the closing off direct sea access, with for example the Maeslantkering, a protective measure to ensure the safety of the hinterland. This protective measure will decrease the open-sea accessibility of the port and hinterland significantly, decreasing its competitiveness. Especially imports and exports will then be hit, and such trade and GDP will decrease significantly.

The region RMDS is a very export intensive region. Zuid-Holland of which the region is part, is the most export intensive region of the Netherlands, with 151 regions it exports to, and 41 billion euros of exported goods (Thissen & Gianelle, 2014). Its trade clustering indicator of 0.33, indicates how much open and widespread the trade relationships of this region are: 'comparatively higher values indicate that the region tends to trade with a closed community of partners (either importers from or exporters to the region), while low values indicate that the region has widespread and differentiated trade partners' (Thissen & Gianelle, 2014).

5.1.1 Adaptation options

A initial exploration is undertaken in a session report of the knowledge program Sea Level Rise for the Region RMDS to examine what the actual measures could be in case of defending the region from significant sea level rise (Defacto, 2021). These solutions are not concrete proposals, but conceptual schools of thought that describe the four cornerstones of possible solutions for addressing the consequences of sea level rise. In this report, four cases are identified, corresponding to the four adaptation options in Haasnoot, Diermanse et al. (2018). The four adaptation options differ especially in their severity of either protecting or retreating. The two 'hybrids' Protect-open and Accommodate will thus likely lie somewhere in the middle of economic impact. To serve clarity in the effects occurring from the adaptation options this thesis only takes the two extremes of these, the most divergent ones Protect closed and Retreat.

Protect

In the Protect strategy, in the RMDS region, the possible spatial developments are shown in Figure 25. In this adaptation strategy, the current coastline remains in its place and the rivers will be closed off to keep the sea out. The water system will be of second priority following and facilitating the current and preferred land use, especially in agriculture and urban areas and, as such, the river water will be pumped out towards the sea.

This adaptation strategy has positive effects on the freshwater supplies in the region. Urban areas will experience a way better water safety through the cutting off from direct sea contact. Furthermore, for a foreseeable future, the current land uses and functions can be facilitated. This means that nothing has to give way, at the cost of some key features, 1) The necessary changes in the water system and the building of dikes which require significant land-use claims 2) The envisioned sea lock in the Nieuwe Waterweg, which replaces the current Maeslantkering, will eliminate the open connection between the North Sea and the Port of Rotterdam. Parts of the port behind the lock will suffer from a loss of deep-sea business but might experience an increase in other port activities. 3) Tidal dynamics and their accessory natural value disappear in the Biesbosch and rivers. Furthermore, the lock prevents fish from swimming and international fish migration. 4) The costs of energy for pumping out the river water takes a lot of energy, which is bad for the environment. 5) Due to the higher river water levels and the associated redirection of the river flows, from north to south, pumping water out results in more subsidence in the polders, eventually causing more salinization at the coastline.

Retreat

In the case of Retreat, in the RMDS region, the possible spatial developments are shown in Figure 26. In this adaptation strategy, the land use will be redirected to serve the characteristics and preconditions that the water system determines. In contrast to the strategy Protect-closed, the water system serves as the leading motive for spatial layout. This means that in this strategy the focus is not on Prevention, recall the DRM cycle, but Mitigation, i.e. keeping the damage of flooding down, and not the probability.

This means in practice that with high water levels, the deepest polders will be allowed to flood. The areas dotted in the south of Rotterdam are (partly) left behind. Here the occurrence of salinization and flood risk will be the reason for people to move to other places. Furthermore, by leaving these areas behind, the Retreat strategy will let the saline water flow freely inwards of land, making drinking water inlets saline. This would mean that retaining rainwater becomes increasingly important and space has to be reserved for this. The recovery of the natural processes such as sedimentation and the usage of the existing elevation levels can be used to fill the Nieuwe Waterweg to dampen the tides and thus decrease high water levels, increase safety and decrease salinization. This however makes deep-sea shipping in the Port of Rotterdam only possible at the coast. Furthermore, the areas between city centres that would suffer enormously from salinization, can be used as areas with saline farming. Note that the Retreat policy only affects susceptible parts of the region, therefore the city of Rotterdam does not have to relocate. This may also be seen in Figure 21, where the Retreat (Meebewegen) indicates how economic and population centres are protected.

Lastly, Retreat delivers a significant cost saving to future generations. In the case of high sea-level rise, the option of retreat saves a lot of money of building ‘stranded assets’ in flood-prone areas, and continuing to protect these flood-prone areas. The developments will likely take place increasingly towards non-flood-prone areas, making it less costly to move further inland when SLR takes its toll. This is assumable because if cities like Rotterdam cannot expand, house prices go up as the population grows. Younger generations will then likely be forced to live in other cities, such as Utrecht close by. This way other centres of economic significance will form further inland.

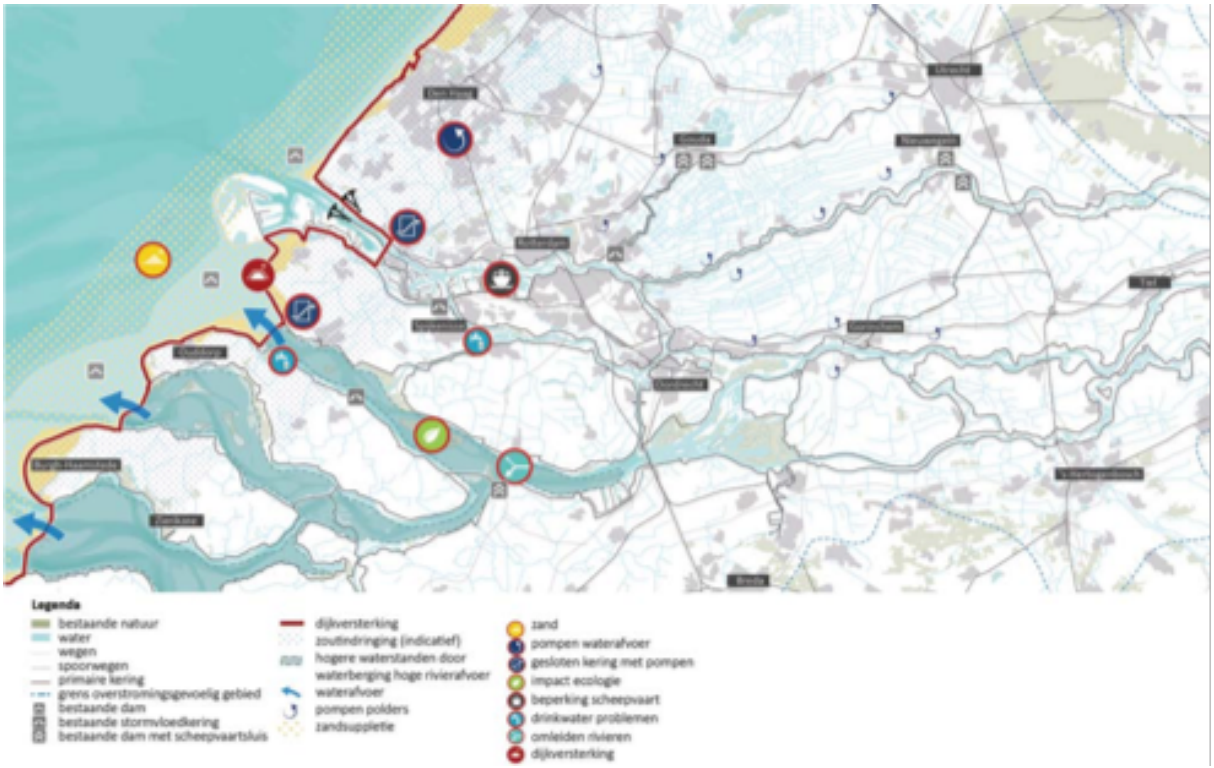


Figure 25; Possible spatial developments in the Protect strategy (Defacto, 2021)

Figure 26; Possible spatial developments in the Retreat strategy (Defacto, 2021)

5.1.2 Here and now

Environment

In the CBS monitor of broader welfare, the dimension Environment is measured in four indicators: nature area per capita, nature and forest area, emissions and swimming water quality (CBS, 2020b). Due to SLR, it is known that damages will occur to nature and forest areas (Brouwer & van Ek, 2004). But also, occasional flooding can have a positive impact on the species of insects, fishes, and plant communities (Hickey & Salas, 1995). Hickey & Salas also mention that 'Without levees, even a great flood...meant only a gradual and gentle rising and spreading of water. But if a levee towering as high as a four-story building gave way, the river could explode upon the land with the power and suddenness of a dam bursting' (Barry, 1997 in Hickey & Salas, 1995). Also, exposure to toxic chemicals in the floodwater; inhalation of mould spores that grow on flood-damaged indoor sheetrock; consumption of contaminated food and water; spread of infectious disease; and the spread of respiratory illnesses decrease the experienced environment. Also, land loss due to storms and increased riverbank heights will lower the ability to enjoy the swimming water and likely also decrease its quality. Emissions are not directly involved with sea level rise effects, but in an adaptation scenario, it is. As there is no evidence on the integral effect of adaptation scenarios on the perceived environment, an objective score can be given to each of the scenarios when certain effects do or do not occur.

A comparison will be made to the reference case 'status quo', which will be used to identify the scenario where no SLR is assumed. When taking into account the risk of flooding and erosion, in the scenario of doing nothing, further referred to as the SLR scenario, a loss of 1 point in environmental quality per effect is used. The negative effects of flooding apply, as there are levees in place which make floods more severe when they happen and prevent occasional flooding with positive environmental effects. As an MCA does not need quantification of effects but purely a score or ranking this method is workable. However, it must be noted that the value is arbitrary. This yields a 2 point loss in the SLR scenario. In this case, a loss of significant loss of environmental quality is expected as many of the existing natural areas exist in tidal river or polder areas such as Tiengemeten and Voorne's and Goeree's dunes which are highly exposed when no adaptation will be applied (Natuurmonumenten, n.d.).

However, in the Protect scenario, less damage will be done to the environment. By shutting off nature from the influences of the sea, such as tides, flooding and salinization, natural areas will be protected from the damages occurring through flooding and erosion. However, by losing the tidal dynamics and its accessory values and preventing fish migration an additional negative effect is created, the creation of dead water which after 80 years still hasn't reached an ecological equilibrium, (Ministerie van Infrastructuur en Waterstaat, 2017). Furthermore, the installation of large water pumps at the coast will cost a load of energy, which will increase with further SLR. This will have negative effects on the environment through greenhouse gas emissions. All in all, the damages that have been prevented by protecting nature and the environment in RMDS are countered by the decrease in fish migration and the emissions of the water pumps. The effect of protection is therefore not a net positive in contrast to doing nothing, but rather the losses remain the same at -2.

However, for the Retreat adaptation strategy, things are looking much better. By taking the forces of nature as they are and leaving the delta open for the influence of the sea, nature will slowly recover into its robust ecosystem. In the case of controlled flooding, it can be assumed that the exposure to toxic chemicals in the floodwater; inhalation of mould spores that grow on flood-damaged indoor sheetrock; consumption of contaminated food and water; spread of infectious disease; and the spread of respiratory illnesses might be prevented. As such, occasional flooding is a positive effect of Retreat on the environment. Overall, the consequences of the retreat will be less damaging to the environment than both previous scenarios. However, due to extensive migration retreat also decreases the consumer base that enjoys the ecosystem services of this environment, leading to a loss in the perceived environment. Every point loss is converted to a 0.1 loss on a scale from 0 to 1 used in the MCA.

Table 8; Scoring table for Environment in RMDS

Effect	**Status quo**	**SLR scenario**	**Retreat**	**Protect**
Flooding	-	-1	1	
Coastal Erosion	-	-1	-1	
Fish migration	-			-1
Waterpump emissions	-			-1
Loss in consumer base	-		-1	
New flood protection	-		1	
Net loss	0	-2	0	-2
Score	**1**	**0.8**	**1**	**0.8**

Safety

The dimension Safety is currently measured in the indicators subjective safety, the number of victims, the number of crimes and domestic violence. However, in the effects of sea level rise, safety will not be affected through any of these indicators. Rather, water safety is more important. Water safety in the Netherlands is measured in safety norms. These safety norms are set on a level of flood risk of a dike trajectory. All primary dikes obtained a safety norm value of 1/300 to 1/1,000,000, where this value is the preferred probability of flooding per year over the dike trajectory. For every dike trajectory thus a flooding probability is determined. This is object to the number of people living behind the dike and the economic value behind the dike (Waterveiligheidsportaal, 2021). It is assumed that in future scenarios this risk approximation is still used. However, in the different scenarios, another adaptation method is used to reach this risk.

This way the Dutch government, as said before, can maintain an individual's death probability of flooding of 1/100,000 per year. In the SLR scenario, when doing nothing, however, this safety level will decrease. For all the citizens in the area that is currently protected by dikes, the risk of flooding will increase as the risk of a dike breach becomes larger when there is a higher sea level. In the areas outside the dike, low-lying areas will more frequently be flooded. However, will this increased flooding also lead to more fatalities and thus safety? In history, the Netherlands has seen many floods (see Table 9) and what can be obtained from this is that the number of casualties has decreased substantially over the centuries (Jonkman, 2007). However, Maaskant et al. (2009) provide the level of increase in the number of fatalities during a flood in Zuid-Holland, the province of the RMDS region. They show that for relatively high population growth in flood-prone areas, the average number of fatalities per year increase by 103% in a SLR scenario, the situation in which no measures are executed to limit the increase of consequence and risk levels (Maaskant et al., 2009). With the same protection level as currently, more people die due to population growth. They also show how building and population growth in flood-prone areas increases the level of fatalities more than when growth is more dispersed, which yields a lower number of 20% increase in fatalities due to SLR (Klijn et al., 2007).

Table 9; Overview of some historical floods in the Netherlands with respect to their loss of life (Jonkman, 2007)

Year	Name	Flooded area	Type / origin	Fatalities
838		Coast, Frisia	Storm surge	
1228			Storm surge	100,000
1287	St. Luciavloed	Waddensea	Storm surge	50,000
1404	1st St. Elisabethsvloed	Vlaanderen en Zeeland	Storm surge	
1421	2nd St. Elisabethsvloed	Southwest Nederland	Storm surge	>10,000
1530	St. Felixvloed	Zeeland	Storm surge	More than 100,000
1570	Allerheiligenvloed	Whole coast: Zeeland, Friesland	Storm surge	20,000
1686	St. Maartensvloed	North- Netherlands	Storm surge	1558
1717		Western coast	Storm surge	11,000
1784		Betuwe, Tielerwaard, Maas en Waal	River	10 tot 20
1809		River area: Ooijpolder to Ablasserwaard	River	275
1825		Noord Holland, Overijssel	Storm surge	305
1855		Betuwe en Land van Maas en Waal	River	13
1861		Bommelerwaard, Land van Maas en Waal	River	37
1880		Land van Heusden en Altena	River	2
1916		Zuiderzee	Storm surge	15
1926		Maas	River	?
1953	Watersnoodramp	Southwest Netherlands	Storm surge	1835

In the SLR scenario, the protection rate remains the same as in Maaskant et al. (2009). Furthermore, it is assumed that population growth takes place at an unrestricted level. Therefore the change in fatalities will be an increase of 103% for the SLR scenario.

Table 10; Estimated changes in number of fatalities in 2040 (Maaskant et al., 2009)

	Lower bound in %	Upper bound in %	Average fatality change in %
Population growth	23	124	68
Sea level rise (0.30 m)	0	40	20
Population growth and sea level rise	23	207	103

In the Protect scenario, however, more protection will be applied to the region. By using further closed barriers such as sea locks, would further increase the safety levels of the people living in the RMDS region. Defacto (2021) mentions that this will bring a strong increase in safety for cities like Rotterdam. However, as the level of safety will only be raised to reach an average of 1/100,000 deaths per year, this will not increase safety more than current levels (Rijkswaterstaat & STOWA, 2017). But will the higher population level then induce more people to die in floods? Because of the fixed probability of dying from floods regulated by law, in the Protect scenario the population increase in the flood-prone areas will not lead to more deaths due to SLR, as the protection will compensate the effect of SLR until this probability of 1/100,000 per year. Therefore, the number of deaths will stay the same as in the status quo.

In the Retreat case, not population growth, but rather population decline is assumed, as people emigrate to other non-flood-prone regions. Probabilities of flooding of dike systems become less important for the safety of citizens as there will be fewer citizens in the area. To keep people safe therefore not the strategy of Prevention of floods is used, but Mitigation as in the DRM cycle. First, again it is assumed that the risk of dying from a flood will stay 1/100,000 years, as flood risk in the Netherlands is regulated by law. So, the government will take care of you until a risk of 1/100,000 per year. However, when floods start to happen more often due to SLR, and people are becoming increasingly engaged in floods, flood risk awareness increases. Baan & Klijn (2004) mention the crises effect, indicating that disaster awareness peaks during and immediately after, but rapidly dissipates between disasters. After some time, worries decrease, and after some years flood risk is again grossly underestimated. Furthermore, the levee effect refers to the fact that once protection measures have been taken, inappropriate high faith in the power of the protection works. People think the dikes will protect them against all future floods and therefore live as if there was no risk. If there were no levee effect and a memory of how a flood would be more private measures would be taken. Therefore in the Retreat scenario, it is assumed that a slight additional improvement in safety is created by citizens themselves. In the RMDS region it is then assumed that in the in 'inundated' municipalities, Alblasserdam, Albrandswaard, Barendrecht, Brielle, Dordrecht, Goeree-Overflakkee, Hardinxveld-Giessendam, Hellevoetsluis, Hendrik-Ido-Ambacht, Krimpen aan den IJssel, Nissewaard, Papendrecht, Ridderkerk, Sliedrecht, Westvoorne and Zwijndrecht, which cover 44% of the inhabitants of RMDS, even more measures are taken that make sure that citizens are not subject to flood risk. It is assumed that 50% of the population will make sure that they do not die in an extreme flooding event, either by moving to a non-flood prone area or by taking other measures. When assumed a 50% migration or mitigation rate, which is approximately analogous with the emigration rate that occurred during Katrina (The Data Center, 2016), 22% of the people in RMDS will leave or further protect the 'inundated' area. Multiplying these, yields a level of 93% of the fatalities of the status quo, and a -6% change in fatalities for the Retreat scenario.

Table 11; Scoring table of Safety in the RMDS

	Status quo	SLR	Retreat	Protect
Population growth		68%	-22%	
Population decline			-22%	
Sea level rise		20%	20%	
Change	0%	102%	-6%	0%
Relative deaths	1	2.03	0.94	1
Score	**0.94**	**0.46**	**1**	**0.94**

Material welfare

In the CBS monitor of broader welfare, the four indicators used are median disposable income and GDP. The expected annual damages (EAD) of flooding in the RMDS region are reported in the work from Koks et al. (2014). They estimate that EAD is 36.1 million euros per year for direct losses in the region and 23.4 million euros per year for indirect losses. Roughly, these two account for 0.022% and 0.014% of GDP in Zuid-Holland (European Commission, 2018b).

De Moel et al. (2013) estimate for the RMDS region that for higher sea levels, for the unembanked areas of RMDS, in 2100 an increase of 112% is estimated. Although this estimate is only made for the areas outside of the dikes, the failure rates of dikes will likely increase equally to the return period of floods over unembanked areas. Therefore, these numbers are employed to project GDP losses in the SLR scenario, where the current protection is used and thus no further measures are taken to remain at the same economic risk (Waterveiligheidsportaal, 2021). Substantial sea level rise, in 2100, will then cause EAD that yields a loss of 0.08% of GDP.

Damage costs are predicted to rise as a result of SLR, resulting in a drop in Material welfare. As a result, a decline is projected in each situation. When implementing the Protect strategy, however, the investments made to raise the level of protection result in a Material welfare loss. But the EAD remain the same as in the status quo, as the government couples the protection level to the economic activity performed behind the protection. Furthermore, water safety in the Protect scenario requires land that is currently used for production. Land as input thus decreases and capital as production factor decreases. Furthermore, the closing of the Maeslantbarrier will decrease the competitive advantages of the Port of Rotterdam, which in the long term also is reflected in Material welfare levels. However, like Husby et al. (2014) put forward, protectional constructions, like the Delta works, have a positive effect on GDP. But also, on the concentration of economic activity in the region. Many of the functions that occur in the region will still be feasible. Only agriculture will suffer from the effects of salinization at the coast, and transport i.e., the Port of Rotterdam will suffer from the closed barriers of the coastal protection. Therefore, a value of material welfare should be higher than the SLR scenario (0,08% GDP loss) and lower than the status quo scenario (0.04%) GDP loss, where the Maeslantkering is less restrictive in transport than a closed barrier will be. Therefore only a small economic decline is expected. Protect scores an assumed 0.06% of GDP loss.

For the retreat scenario to the current economy, much more land loss is necessary. Giving up traditional agriculture in the region where salinization will take place and letting go of areas that are easily inundated for production and consumption has an even more negative effect than the EAD that occur during floods. Partly this is also due to that reconstruction of these damages is also part of GDP. Retreat especially decreases material welfare through migration. The loss of the critical mass that is the agglomeration of Dordrecht decreases productivity by a lot. Agglomeration effects such as the presence of a large market for labour and inputs and outputs disappear. Therefore, the assumption of an even larger Material welfare loss is taken. When retreating in the RMDS region, several areas are (partly) lost. Although the retreat especially takes place in the agriculturally dominated areas of the region, also cities like Dordrecht will suffer. Furthermore, from the retreat scenario, the sedimentation in the Nieuwe Waterweg will make sure that shipping is restricted inland. This means a decrease in the competitiveness of the Port of Rotterdam. This will eventually lead to large income reductions. All in all, the effect will be larger than the losses in the SLR scenario, hence at least a value of 0.08% GDP loss is expected. To keep the same order of magnitude in the effects, a further step from 1 is taken to a level of 0.1% GDP loss.

Table 12; Scoring table Material welfare RMDS

Scenario	**Status quo**	**Status quo in % GDP**	**SLR in % GDP**	**Retreat in % GDP**	**Protect in % GDP**
Factor SLR			212%		
GDP Zuid-Holland	€ 163,800,000,000				
Direct damages	€ 36,100,000	0.022%	0.047%		
Indirect damages	€ 23,400,000	0.014%	0.030%		
Total effect	€ 59,500,000	0.04%	0.08%	0.1%	0.06%
GDP scenarios		0.9996	0.9992	0.9990	0.9994
Score		**1**	**0.9996**	**0.9994**	**0.9998**

Jobs

The dimension of jobs indicates the level of employment opportunities in the region. In CBS's monitor of broader welfare, the indicators used are the labour participation rate, unemployment rate, vacancy rate and percentage of highly educated workforce. However, to simplify the interpretation of the magnitude of the three different scenarios, the indicator 'number of jobs' will be used. The number of jobs for both regions in December 2019 is obtained from the CBS (2020a) for both regions in this thesis.

The first sector, Agriculture, is highly affected by sea level rise and accounts for 1% of all jobs. As the municipalities where agriculture is most prominent are inundated or affected by salinization, agriculture loses more than half of its current area (see Figure 27). Therefore, a decrease of 3 points on a scale of -5 to +5 can be expected. In the Retreat scenario, this decrease will pursue as no more protection measures are taken to decrease salinization in the area. But in the Protect scenario, decreases in the agricultural area due to salinization will only affect coastal agriculture (see Figure 26), which yields a decrease of 1. In the longer term, however, agriculture in the deepest polders is also affected because salinization from the groundwater will then be the problem. Long term number of jobs will thus decline by 2 in Agriculture.

The second important sector is Industry, which is impacted through the losses of salinization and damages towards industry assets and accounts for 6% of jobs. In the port area of Rotterdam and Dordrecht, many industrial jobs are located. If in these areas the costs of operating, due to damages or salinization might become too high, companies might move further inland. Therefore, an endured effect on jobs can be expected. In the SLR scenario, 2 points of decrease are expected. In the Retreat scenario when the strategy serves as a signal to investors that the area is unsafe, this decrease will be larger by 3 points. In the Protect scenario, only the costs of salinization might induce companies to move away, as such only a 1 point decrease is expected. Construction, due to rebuilds of flood damages has a positive impact on jobs and currently accounts for 5% of jobs. These flood damages are recurring and thus a permanent increase in construction work of 3 will be applied in the SLR scenario. In the Retreat scenario, however, reparations will likely not be made and new construction will take place further inland. Therefore, a loss of -3 will be applied, as parts of the protected areas likely still need construction for replacements. In the Protect scenario, in the region, enormous investments for coastal protection will take place. This will likely increase the short-term demand for construction labour, but due to maintenance, this demand will likely remain high in the long term. Therefore, a permanent increase in construction work of 5 points is expected.

Trade and logistics will both be suffering from the effects of SLR. Especially when damages in the port and its associated supply chains disruptions cause losses, jobs might disappear. Due to SLR, these damages will start to recur and as such, companies might leave the area for a more competitive one. In this sector, a decrease of 2 points is applied. This again permanently decreases the number of jobs in the area. In a retreat scenario, this company exodus might be even larger when companies are incentivized by lower safety norms to leave. Therefore, a larger decrease of 3 points is applied. In the Protect scenario, increased investment and economic activity due to increased protection levels and construction will increase the number of jobs in trade and logistics together. As the RMDS region is already a logistical powerhouse, the increase associated with it will be large, due to agglomeration (scale) economies. Therefore, a large increase of 4 points will be awarded to the trade and logistics sectors in the Protect scenario.

In the Real estate sector in the RMDS region, a significant decrease in the number of jobs is expected due to SLR. Although only 1% of the jobs is in Real estate, the prices of houses go down a lot when the increase in risks of flooding is starting to be perceived. Bernstein et al. (2017) already saw evidence for a decrease in prices of real estate in flood-prone areas. They estimated a price effect of -7% for houses that are flood exposed and a 4% discount for housing that will not be flooded until 100 years from now. In the case of SLR, these prices will likely go down even more (Bloomberg, 2020). If a large decrease in housing prices is expected in the region the number of real estate jobs will likely decrease as well, due to decreased real estate investments in the region. In the SLR scenario, the order of magnitude in the price decrease is in tens of per cent, if we assume a more severe price effect than is currently measured in the United States. Dolfman et al. (2007) measure the effect of a decrease of over 50% in Real estate jobs after the Hurricane in 2006. Therefore, also a decrease in real estate jobs in tens of per cent is expected. Therefore, a decrease of 2 is expected, which in the end reflects a decrease of 40% in real estate jobs.

When the Retreat strategy is adopted, however, even further decreases in prices will decrease the level of Real estate jobs even more. Therefore a 3 points decrease is applied. When the strategy of Protect is used, the region will likely not experience a decrease in house prices, as protection will prevent flood risk. Also, more growth of economic activity can be expected. Either due to increased protection levels or increased investment, growth of demand for housing can be expected, which lead to an increase in jobs for the Real estate sector. This yields a 'same order of magnitude' growth as in the SLR scenario, and thus the Protect scenario will receive a 2 point increase in the sector of Real estate jobs. In the Retreat scenario, not only the sectors that are directly engaged with the effects of SLR will be hit, but also the sectors that suffer from the effects of migration, brain drain, and all other negative effects of the Retreat scenario. Therefore, all the other sectors that are mainly supportive of the sectors that are directly involved with the effects of SLR will be given a decrease of 1 point in the Retreat scenario. The sectors that are business supportive are Energy, Utilities, IT, Finance, Business services, Rental services, Public management, Education and Healthcare.

Table 13; Impacts on jobs in individual sectors in the RMDS region

Sector	Share (status quo)	Impact SLR	Retreat	Protect
Agriculture	1%	-3	-3	-2
Mining	0%			
Industry	6%	-2	-3	-1
Energy	0%		-1	
Utilities	0%		-1	
Construction	5%	3	-3	5
Trade	17%	-2	-3	4
Logistics	8%	-2	-3	4
Hospitality	5%			
IT	3%		-1	
Finance	3%		-1	
Real Estate	1%	-2	-3	2
Business services	7%		-1	
Rental services	14%		-1	
Public management	6%		-1	
Education	6%		-1	
Healthcare	16%		-1	
Recreation	2%			
Other services	1%			
Total	100%	**-10%**	**-34%**	**24%**
Relative no. jobs	1.00	0.90	0.66	1.24
Score	**0.81**	**0.72**	**0.53**	**1.00**

Institutional quality

The dimension of Institutional quality might not seem as affected by the effects of sea level rise. However, the inequality that is caused by the effects of SLR and adaptation possibilities do require fair government action. Furthermore, institutional and societal barriers are in place when adapting to SLR (Hinkel et al., 2018). Therefore, the dimension of institutional quality is affected by SLR.

Institutional quality is a broad concept that captures law, individual rights and high-quality government regulation and services and it reinforces economic development over the longer term (RaboResearch, 2016). Institutional quality in the CBS monitor of broader welfare is comprised of the indicators trust in institutions, trust in others and the percentage of the working population that performs social work. Lack of trust might lead to all sorts of negative consequences, as the foundations of the economy are built on trust (see also Rodríguez-Pose (2018)). An example of how SLR can reduce or increase this trust is the current Covid-19 pandemic. In 2020 the trust in institutions showed a strong increase (Centraal Bureau voor de Statistiek, 2021). In Akbar & Aldrich (2017) the effects of the 2010 Pakistan floods on how residents see their decision-makers is measured. They find that high material loss during the flood was negatively correlated with post-flood trust levels. In contrast, housing stability and perceived fairness in the distribution of disaster aid were positively correlated with post-flood levels of trust. Unfairness and Material loss are thus drivers of distrust. In this MCA the scenarios of SLR and adaptation will be classified based on those two drivers. When SLR gets underway, as seen in Figure 2, the SLR will have an exponential pace. This means that when investments need to happen, these have to be made at increasingly larger scales. When governments are unfit for the job, the unfairness and material loss will drive distrust.

In the status quo, the trust in the government in the RMDS region is assumed to be 1 as the reference case. In the case of SLR, when doing nothing against the increased flood risk and effects of SLR, trust in institutions will likely go down. The people that live in the area will think that not helping them is unfair. In Akbar & Aldrich (2017) the constant of the OLS regression used is 2.516, the coefficient for perceived fairness is 0.795, significant at $p<.001$. This means that when a policy is unfair, Institutional trust decreases by 0.795 holding all else equal, which is a decrease of 24%. Material loss is also one of the predictors of post-flood social and institutional trust, with a coefficient of -0.189, significant at $p<.001$. Holding all else equal, when a material loss has incurred the level of institutional trust decreases by -0.189, which is a decrease of 8%. The maximum value that can be obtained in a situation where there is perceived fairness and no material loss, yielding a value of 2.516 + 0.795 = 3.311. Doing nothing in the SLR scenario is likely perceived as unfair, furthermore, material loss is at the highest level among the three options, due to low protection and no retreat. Holding all else equal, this yields a value of 2.516 – 0.189 = 2.327. This is a decrease of 30%. Hence a value of 0.7 is used to describe Institutional quality in the RMDS region using a SLR scenario.

In the Retreat scenario, likely also institutional trust will decrease. In the Retreat strategy, people in the protected area in RMDS will benefit more than the people in the 'inundated' area. A perceived unfairness thus arises. However, this loss in trust will not go to waste as the material loss due to flooding is bound to decrease for the people in the unprotected areas. As such in the same regression model the perceived fairness is switched off and the material loss as well, as the strategy is unfair and has decreased material loss. This yields a value of 2.516

which is 24% lower than the maximum value. Hence a value of 0.76 is used to describe Institutional quality in the RMDS region using the Retreat scenario.

In the Protect scenario, the trust remains high in the area. Protect is the fairest option for all citizens, as not many inhabitants will be displeased by the Protect scenario. As the popular Dutch saying goes, there are no left-wing or right-wing dikes (Keessen et al., 2013). Also, the material losses will be at the most preventable level by an abundance of protection measures, when everything is assumed to go perfectly as planned. However, as previously mentioned, the investments have to follow each other up at increasing scales, making it hard for the government to stay ahead of the SLR. If due to financial barriers (Hinkel et al., 2018), the Protect scenario does fail, Material loss will be much higher than in the other scenarios, due to no private mitigation. Therefore, the Material loss will be put into practice as well, and the Institutional quality will be at the level where all switches are on, with a score of 0.94.

Table 14; Scoring table of Institutional quality in RMDS

	Status quo	SLR	Retreat	Protect
Constant	2.516	x	x	x
Perceived fairness	0.795			x
Material loss	-0.189	x		x
Maximum	3.311	2.327	2.516	3.122
Score	**1.00**	**0.70**	**0.76**	**0.94**

Housing

The overheated housing market in the Netherlands is one of the major problems that currently need to be addressed. Unfortunately, sea level rise effects could prevent even more people from having a place to live. Due to flood risk, housing prices in affected areas will become very low as nobody wants to suffer the risks anymore. In safer places, the housing prices will go up causing poorer people to live in vulnerable areas, and richer people to live in safer places. The dimension Housing in the CBS broader welfare monitor includes three indicators to measure the housing circumstances in a region; satisfaction with the living environment, satisfaction with the home and distance to amenities.

The housing stock is unequally distributed in the area (see Table 15). Housing stock numbers are the end stocks from January 2021 and obtained from CBS for both regions in this thesis (2021c). The areas that will quickly and deeply inundate during a flood are deemed a bad location to live. Therefore, from Figure 24, it is derived which municipalities are most likely to be inundated. The municipalities that show entire inundation are given the value of -4 on a scale from -5 to 5, which corresponds with an 80% decrease in the housing stock. The municipalities with -3 are less so but still more than half-inundated and the city of Rotterdam and Capelle aan den Ijssel are only partly inundated. Furthermore, it can be expected that by not taking any stance against SLR, expected building programs in the area will likely continue. In the coming years, in the region of RMDS, the aim is to build 22% of the ca. 1 million houses that are planned in the coming 20 years. These houses are planned in and around the cities, Rotterdam (>25,000 new houses) Dordrecht (10,000-25,000 new houses) (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2021). These houses are aggregated regionally, and as such a division is made to divide the new houses. 25,000 will be divided over Rijnmond’s municipalities and 15,000 over Dordrecht's, weighed on the existing housing stock in both parts of the region. Applying the scores to the new housing stock will yield a score of 0.72.

In the Retreat case, not only the municipalities that show vulnerability to sea level rise will be locations that are not habitable, but also the polders directly below Rotterdam will be used as floodplains or water storage areas, serving the water system. It is assumed that not all housing in the area will have to make way, but at least to limit the damage, housing not be built in lower-lying parts. This makes that about 60% of the room where housing exists in the polders today will be inhabitable. The decrease of room for housing will decrease the housing stock with a -3 value correspondingly. Furthermore, new housing projects are not pursued as in the Retreat scenario new investments will likely only take place in areas unaffected by SLR. Therefore, the current housing stock is used to calculate the expected stock in the Retreat scenario. This yields a score of 0.44.

When protecting the RMDS region against SLR, a different development takes hold. According to Defacto (2021) in the Protect scenario, many of the existing functions can remain to exist, including housing. A redistribution of housing is not necessary, however, it is likely that developments needed to address the current housing problem, will increase the housing stock in the area, as now they are protected and thus safe to develop on. This follows the safe development paradox logic also referred to in Husby et al. (2014) and Haer et al. (2020). Therefore, in the Protect scenario, every region that has obtained an increase in protection will continue to receive development. Using the new housing stock that has increased by around 5% from the current stock, yields the highest score of 1.

Table 15; Scoring table Housing in the RMDS municipalities

Total Drechtsteden	130,352
Total Rijnmond	621,248
Extra Drechtsteden	15,000
Extra Rijnmond	25,000

Municipality	**Housing stock**	**Share**	**Weight**	**Extra houses**	**New housing stock**	**New share**	**Impact SLR**	**Retreat**	**Protect**
Alblasserdam	8,408	1%	6%	968	9,376	1%		-3	12%
Albrandswaard	10,573	1%	2%	425	10,998	1%		-3	4%
Barendrecht	19,433	3%	3%	782	20,215	3%		-3	4%
Brielle	8,110	1%	1%	326	8,436	1%		-3	4%
Capelle aan den IJssel	31,556	4%	5%	1,270	32,826	4%	-1	-1	4%
Dordrecht	55,813	7%	43%	6,423	62,236	8%	-3	-3	12%
Goeree-Overflakkee	22,098	3%	4%	889	22,987	3%		-3	4%
Hardinxveld-Giessendam	7,514	1%	6%	865	8,379	1%	-4	-4	12%
Hellevoetsluis	18,067	2%	3%	727	18,794	2%		-3	4%
Hendrik-Ido-Ambacht	12,332	2%	9%	1,419	13,751	2%	-3	-3	12%
Krimpen aan den IJssel	12,648	2%	2%	509	13,157	2%		-3	4%
Lansingerland	24,686	3%	4%	993	25,679	3%			4%
Maassluis	15,389	2%	2%	619	16,008	2%			4%
Nissewaard	39,469	5%	6%	1,588	41,057	5%	-3	-3	4%
Papendrecht	14,479	2%	11%	1,666	16,145	2%	-4	-4	12%
Ridderkerk	21,308	3%	3%	857	22,165	3%		-3	4%
Rotterdam	317,945	42%	51%	12,795	330,740	42%	-1	-3	4%
Schiedam	37,472	5%	6%	1,508	38,980	5%			4%
Sliedrecht	11,086	1%	9%	1,276	12,362	2%	-4	-4	12%
Vlaardingen	35,551	5%	6%	1,431	36,982	5%			4%
Westvoorne	6,943	1%	1%	279	7,222	1%		-3	4%
Zwijndrecht	20,720	3%	16%	2,384	23,104	3%	-4	-4	12%
Total	751,600	100%	200%	40,000	791,600	100%	-24%	-51%	5%
Total scenarios	751,600						600,669	368,738	834,332
Score	**0.90**						**0.72**	**0.44**	**1.00**

5.1.3 Future generations

In the CBS monitor of broader welfare, also the future generations are considered. As sea level rise is especially a future problem, the dimensions deemed to be important to future generations will be scored as well.

Economic capital

The dimension Economic capital comprises the indicators of debt and wealth per household. However, in this dimension, this thesis uses another approach. Whereas debt and wealth in current levels do result in future capital gains or interest payments, for the impact of sea level rise on future generations not only capital is important. On the contrary, considering the safe development paradox, capital in a place that will be inundated is more of a burden than an asset. The development of assets in locations that are not futureproof will lead to future costs and not gains. Therefore, in this dimension, another approach is used. Rather than the net value of economic capital, this thesis uses the concept of resilience.

Resilience is the quality of being able to return quickly to a previous good condition after problems. In this case thus the ability to return to the same welfare level after a flood. This can either be reached by making internal (i.e., adaptive) adjustments in human systems, for example by migration or external (i.e., manipulative) adjustments, such as coastal protection.

Thomsen et al. (2012) make a distinction between adaptive and manipulative options of adaptation and argue that internal adjustments present much more learning opportunities and prospects for building adaptive capacity and ensuring a sustainable future.

Protection requires significant ongoing management and investment, with the potential to impact negatively upon other system components. Furthermore, it creates a path dependency. The example of Noosa, Australia shows that protective strategies have resulted in the development of new system equilibria and the need for ongoing beach management. The costs incurred for protection and the negative external impact increases the social-ecological stress over time while reducing the learning opportunities to adapt. The protect options based upon manipulative are thus likely to be short term in effect and are expensive in the longer term, eventually leading to system collapse (see Figure 27).

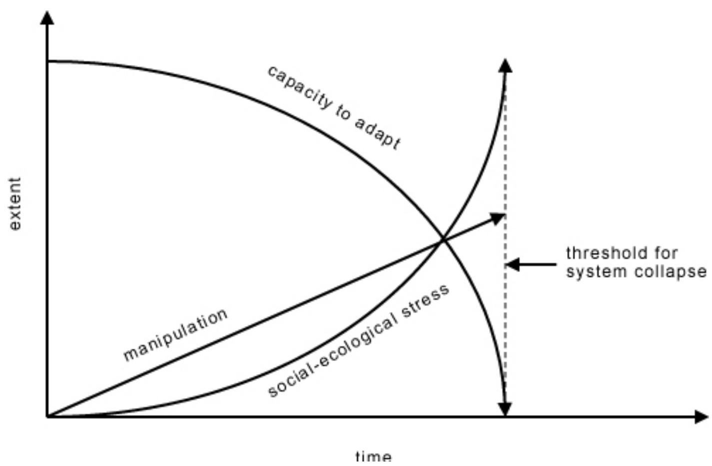


Figure 27; Relationship among manipulation, adaptive capacity, and social–ecological stress. (Thomsen et al., 2012)

In Rotterdam, the biggest city of the RMDS region, resilience is not uncharted territory. In their Resilience Strategy, they show that for climate resilience, many of the initiatives offer only short or medium-term benefits and learning is still the goal instead of large scale resilience (Gemeente Rotterdam, 2016).

But how can we measure resilience? The City Resilience Index shows an assessment of the current ‘capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience’ (Gemeente Rotterdam, 2016). Figure 28A shows the 12 most important aspects of the city as a system, as shown in the City Resilience Framework. Figure 28B shows an assessment of the inventory of actions and programs contributing to these aspects. It can be perceived that especially long term and integrated planning needs to do better. Also, economic prosperity is a point of attention.

To ensure economic prosperity in the long term, long term objectives are necessary. In the current situation, as shown in Figure 28B, the long term is not addressed enough. As the City Resilience Framework does not offer a single index-value for the city of Rotterdam, a qualitative value is given. In the status quo, the position of resilience with rights to sea level rise is ‘medium’ on a scale from ‘bad’, ‘medium’ to ‘good’.

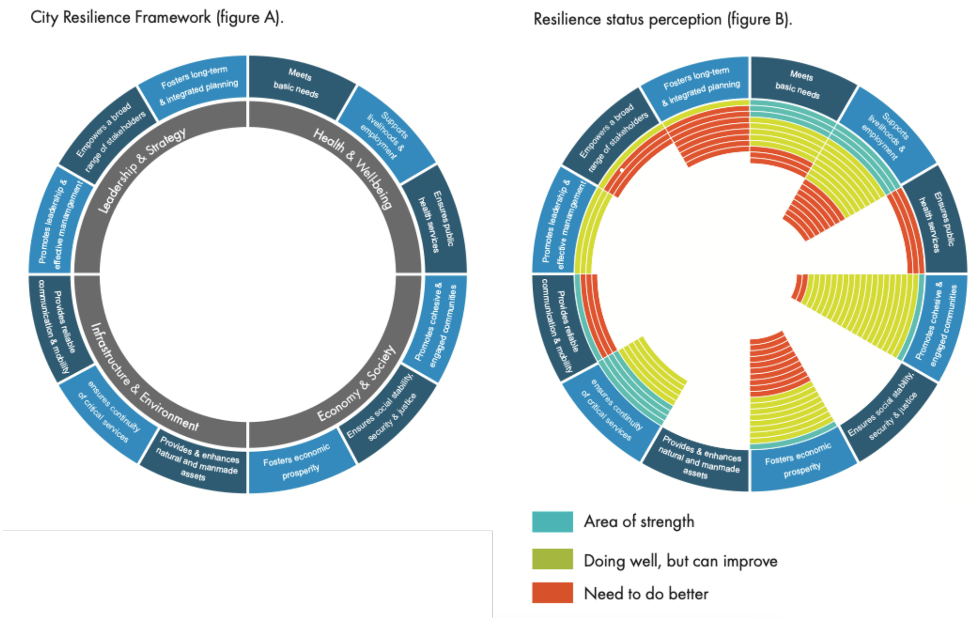


Figure 28; City Resilience Framework assessment of Rotterdam

In a SLR scenario, where not much more will be done against the effects of SLR than currently, resilience decreases. As the long term comes closer when moving into the future, the current status does not offer much to remain resilient in the long term. As such, in a SLR scenario, the qualitative value goes from ‘medium’ to ‘bad’.

In the Retreat scenario, future resilience will rise, following the argumentation of Thomsen et al. (2012). Therefore, the value will rise to ‘good’.

In the Protect strategy, the city and region will increase their path dependency and social-ecological stress (see Figure 27) and as such it will become increasingly harder to remain the quality of being able to return quickly to a previous good condition after problems. Therefore, the Protect strategy is 'bad' in terms of resilience in the long term. If the fuzzy set of 'bad', 'medium', 'good' is converted to numerical values it will yield the scores 0, 0.5 and 1 respectively. As such the scores of the different scenarios are denoted in Table 16.

Table 16; Scoring table Economic capital in RMDS

	Status quo	**SLR**	**Retreat**	**Protect**
Resilience	Medium'	Bad'	Good'	Bad'
Score	**0.5**	**0**	**1**	**0**

Natural capital

Natural capital, in the CBS monitor of broader welfare, includes many of the same indicators used for the dimension of Environment. However, the Natural capital dimension these are measured not to offer current value, but value to future generations. In the Environment dimensions for each of the scenarios, it was determined how natural areas will be affected by different scenarios of adaptation. However, most of the impacts of floods, erosion and salinization and the impacts of the closing of the Dutch delta are short-lived effects on nature. Nature has shown to be very resilient, and soon after closing off deltas, new ecological equilibria arrive, such as in Zeeland (Deltawerken Online, n.d.).

In Brouwer & van Ek (2004) a comparison is made between the scenarios Protect and Retreat in their contribution to nature conservation policies in the RMDS region. They show that for a SLR scenario in 2050, the Retreat option, consisting of floodplain restorations, natural capital is 22.2% more than the reference case, the SLR scenario. They name the ecological impact of dike strengthening as negligible and hence give it the value zero. This would yield a 1 for the SLR scenario, a 1.22 for the Retreat scenario and a 1 for the Protect scenario. However, in the dimensions that were handled before, more substantial sea level rise is considered as well. While there are no studies that look at natural capital in a more severe SLR scenario, it can be deducted from Defacto (2021b) that retreat offers more chances for nature than Protect, and Protect does have several negative consequences, such as the negative effects occurring due to fresh-salt water gradients and the intertidal values of nature serving as nurseries for fish and birds. Therefore, for Protect a negative value is adopted.

For the SLR scenario, also intertidal areas disappear. Therefore, it is a worse scenario than the status quo, thus the status quo will obtain a slightly higher value at 1.1. The SLR scenario will obtain a lower value than the SLR scenario, which has a value of 1 and thus gets a 0.9. The resulting MCA values are shown in Table 17.

Table 17; MCA scores Natural Capital

	Status quo	**SLR**	**Retreat**	**Protect**
Natural capital	1.1	1	1.22	0.9
Scores	**0.9**	**0.82**	**1**	**0.74**

Human capital

The last dimension belonging to the broader welfare in the RMDS region is Human capital. Human capital in the CBS monitor of broader welfare is indicated by the number of worked hours per week, the percentage of highly educated people, life expectancy and experienced health. In other words, what humans contribute to future value added. In the context of sea level rise, especially migration plays a big role in this dimension. When migration causes especially high-income workers to relocate into safer areas, the concept of brain drain takes hold (Docquier & Rapoport, 2012). Therefore, to the different scenarios, different levels of expected human capital belong.

In the status quo, human capital levels in the region are at a reference level, value 1. When sea level rise happens, one of the major consequences is the migration of people out of the affected area. In Perch-Nielsen et al. (2008) this is supported. Through lost income, damages to buildings, reduced access to drinking water and loss in agriculture yield people feel the need to relocate. Black et al. (2011) identify other migration drivers and propose that these drivers are enforced by environmental effects. Environmental, Political, Social, Economic and demographic characteristics are of influence on the decision to migrate. And this migration might lead to 'brain drain', but also to positive network externalities (Docquier & Rapoport, 2012). Considering only human capital, migration is not a good thing for the sending region. Especially given the fact that highly educated people are more likely to evacuate or migrate indefinitely, brain drain might cause human capital to decrease.

In the SLR scenario, it is assumed protection is not increased from current levels and as such major disasters might start to happen. Therefore, the degree of destruction that occurred during Katrina in New Orleans might be similar to a future storm surge in the RMDS region. This might mean that in the wake of the disaster in the region, a similar order of magnitude of human capital has fled. During and after Katrina over 50% of the people fled. By 2015, 15 years later, the population recovered to only 80% of what it was in 2000 (The Data Center, 2016). In the region, RMDS unprotected areas might likely suffer the same degree of outmigration. The share of people living in unprotected areas, which, in a SLR scenario is estimated to be around 30% of the citizens based on Figure 25 and the number of people living in these areas (see Safety). Therefore, a degree of permanent outmigration (20% of 30%) is expected to be 6%. This 6% decrease will yield a score of 0.94.

The effect of forced migration can be reduced by migration due to retreat. In the Retreat scenario, it is assumed that fewer people have to permanently migrate, as there is more space reserved for water to flow into. Therefore, when retreating a decrease of 44% of the population can be expected, which is the population of the land area that is 'inundated' in the map in Figure 27. Likewise, as in the previous scenario, it is assumed that 80% of the people will return. In the Retreat scenario thus a level of permanent outmigration is 8,8% (44% of 20%). This yields a score of 0.912.

In the Protect scenario, even fewer people have to migrate or evacuate. It can be assumed that when protection is the strategy, everyone can remain in the same location. Functions do not have to make way for the water, as these functions are the leading principles for protection. This means that in the Protect scenario, all citizens can remain permanently and the level of human capital is at the reference level, value 1.

Table 18; Scoring table Human capital in RMDS

	Status quo	SLR	Retreat	Protect
Share of population affected	0%	30%	44%	0%
Permanent outmigration rate	20%	20%	20%	20%
Population decrease	0%	6%	9%	0%
Score	**1**	**0.94**	**0.91**	**1**

5.1.4 Results Rijnmond-Drechtsteden

In this section, the outcomes of the MCA in the RMDS region is given. The results of the MCA are shown in Table 19. In the MCA, the status quo scored the highest with a score of 6.9. Note that this is a sensible result, as no SLR is assumed and no sacrifices have to be made yet. The score of the SLR scenario is the lowest of the four; 5.3. This again is a logical result, as adaptation is not used to prevent the effects of SLR. The two Adaptation strategies score higher, with 6.6 for Retreat and 6.3 for Protect. This means that Retreat is the preferred option of adaptation to SLR in the RMDS region.

Table 19; Results of the MCA for RMDS

Dimension	Status quo	SLR	Retreat	Protect	Weights
Environment	1.00	0.80	1.00	0.80	0.92
Safety	0.94	0.46	1.00	0.94	0.92
Material welfare	1.0000	0.9996	0.9994	0.9998	0.86
Jobs	0.81	0.72	0.53	1.00	0.84
Institutional quality	1.00	0.70	0.76	0.94	0.67
Housing	0.90	0.72	0.44	1.00	0.92
Economic capital	0.50	0.00	1.00	0.00	0.855
Natural capital	0.90	0.82	1.00	0.74	0.855
Human capital	1.00	0.94	0.91	1.00	0.855
Score	**6.9**	**5.3**	**6.6**	**6.3**	AVG = 0.855

In the MCA of the RDMS region, certain dimensions have shown to score high in certain strategies. In the Retreat strategy, these were Environment, Economic capital and Natural capital. In this section, these driving dimensions will be discussed.

To the dimension of the Environment, Retreat has the highest value because retreating means that the water system is decisive for the layout of the region. This has as a consequence that the sea and its natural ecosystem will be allowed to come farther inland. Despite the damages occurring through increased flooding and coastal erosion, no 'dead water' is created and no large scale fish migration is hindered by the Retreat option. Also, the potentially catastrophic effects of dike breaches, identified by Barry (1997) in Hickey & Salas (1995) are prevented.

In the dimension Economic capital Retreat scores highest among the three because of the reasoning of Thomsen et al. (2012) that Retreat offers more learning opportunities build adaptive capacity and ensure a sustainable future. Protection requires more ongoing investments and as such, economic capital to ensure welfare (in the narrow or broader sense) will be limited.

For the dimension of Natural capital, which is closely linked with enjoying the value of nature and the environment in the future, Retreat scores well. Because of the restoration of floodplains, a contribution to nature conservation policies in the RMDS region is offered (Brouwer & van Ek, 2004).

Nevertheless, the Protect strategy also scores high on certain dimensions. Especially Jobs, Housing and Human capital do well. Jobs show an increase in the RMDS region. This is because economic activity can continue and further investment in Protection also provides stimulus to the region's economic activity. Housing also is increased in the Protect in contrast to the other scenarios. The region of Rotterdam is expected to have a growing population and plans to build will provide this in the Protect scenario, whereas in the Retreat scenario building would take place elsewhere to supply housing to a growing population. Human capital also does well, as no people are forced to move out of the region because of SLR reasons such as flood risk.

Different strategies could have been favoured if only a few dimensions of welfare were considered. Protect would be preferred if only Material welfare was considered, 0.9998 over 0.9994. If only the three most heavily weighted variables, Environment, Safety, and Housing, would be examined it would also result in Protect as the recommended strategy (see Table 20).

Table 20; Using only the three most important dimensions for MCA of RMDS

Dimension	**Status quo**	**SLR**	**Retreat**	**Protect**	**Weights**
Environment	1.00	0.80	1.00	0.80	0.92
Safety	0.94	0.46	1.00	0.94	0.92
Housing	0.90	0.72	0.44	1.00	0.92
Score	**2.6**	**1.8**	**2.2**	**2.5**	AVG = 0.920

5.2 Frisian Wadden-coast

The region of the Frisian Wadden-coast is a region of economic decline (Ministerie van Algemene Zaken, 2019) and comprises the municipalities of Harlingen, Noardeast-Fryslân and Waadhoeke (or in older municipal divisions; Harlingen, Franekeradeel, het Bildt, Menaldumadeel (Menameradiel), Littenseradeel, Dongeradeel, Ferwerderadeel, Kollumerland and Nieuwkruisland). Agriculture is the principal land-using economic activity in the region, and it is thus particularly vulnerable to the effects of sea level rise through salinization. However, the an additional Delta program proposes to strengthen the economic position of the Netherlands' north by constructing the Lely-Railtrack, a faster connection from the Randstad to the north, and by constructing a significant number of houses (Provincie Groningen, 2021). In the Climate risk estimator for the Frisian Wadden-coast region, a map shows which locations have a high danger of flooding, with green indicating low risk and yellow indicating high risk (Klimaatschadeschatter, n.d.).

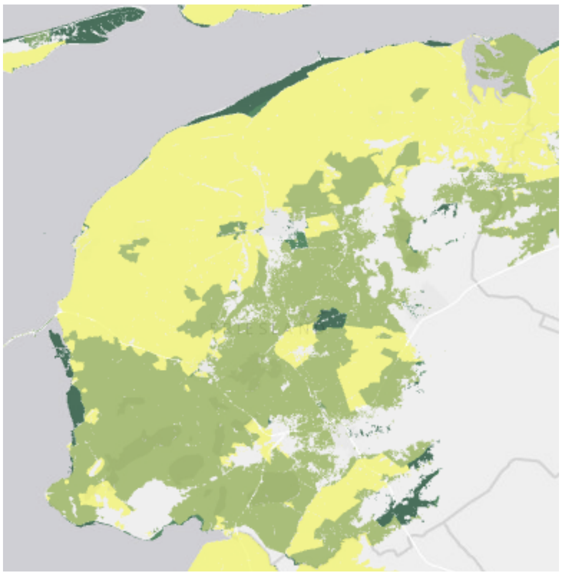


Figure 29; Inundation heigths for Frisian Wadden-coast

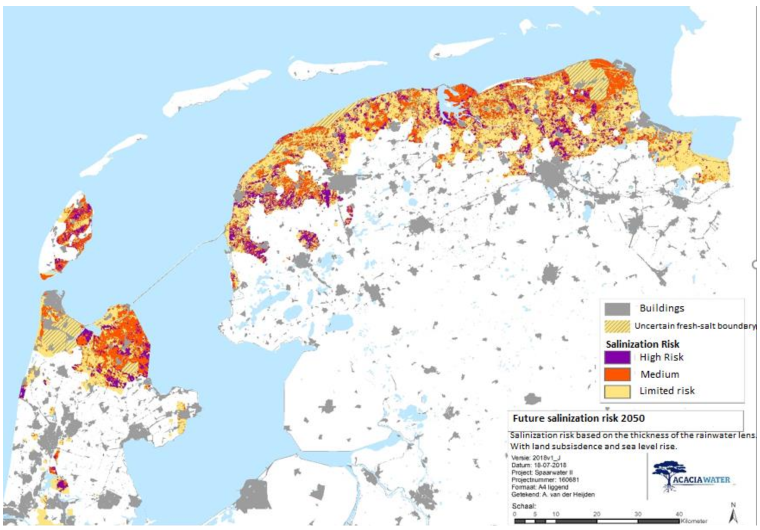


Figure 30; Future risk of groundwater salinity for 2050 (AcaciaWater, 2017)

As can be seen from the map, almost the whole Frisian Wadden-coast is under threat of flooding. The predominantly green part in the north is a wetland area and can be inundated without causing much damage. However, there is a risk of inundation, the Wadden-islands and wetlands serve as coastal protection (Duin, 2015). In Tzemi et al. (2020) a salinization map is made for this region. Figure 30 shows that the whole Frisian Wadden-coast area will suffer, with high, medium or limited risk, from the consequences of salinization.

For the effect of coastal erosion, this region is not as vulnerable, as the region has increased protection by the Wadden-islands and wetlands (Duin, 2015). The Wadden Sea serves as an important coastal flood defence mechanism, by providing a 'shield' of barrier islands, tidal flats and shallow waters that act as a buffer to reduce the forces from the North Sea on coastal protection structures (Baarse, 2014)

The region of Frisian Wadden-coast is less of an export intensive region. In contrast to the RMDS region, the number of export destinations of 26 is about six times as small. Also, trade volumes are much lower, with 3.1 billion instead of 41 billion in exports. Also, the trade is much more clustered around a closed community of partners, with a value of 0.82 (Thissen & Gianelle, 2014).

5.2.1 Adaptation options

In the session report from the knowledge program for sea level rise for the Wadden Sea region, the options for adaptation are explained (Defacto, 2020).

Protect

In the Protect strategy, the same coastline is used as it is today. The spatial developments that take place when the region is protected against sea level rise are shown in Figure 31. In the Protect option, the water follows the current land uses. From Figure 31 it can be obtained that most of the Frisian Wadden Sea coast will thus remain the same. This means that the space that remains available can be used for the growing need for housing. However, still, some problems remain. There will be a spatial conflict of the strengthening of dikes in the city of Harlingen and the increased level of salinization will cause agricultural infertility on the coast.

Retreat

In the Retreat strategy, more effects of SLR occur. The spatial developments that take place when the region retreats due to sea level rise are shown in Figure 32. In this adaptation strategy, the land use will be redirected to serve the characteristics and preconditions that the water system determines. In contrast to the strategy Protect the water system serves as the leading motive for spatial layout. This means concretely that the northern coast will be predominantly used as salt marshes to decrease the forces of the sea. Where first a high density of croplands dominated the landscape in the region, now salinization which due to the salt marshes flows farther inland, traditional crops will not be viable and other land uses have to be found.

Figure 31; Possible spatial developments in the Protect strategy (Defacto, 2020)

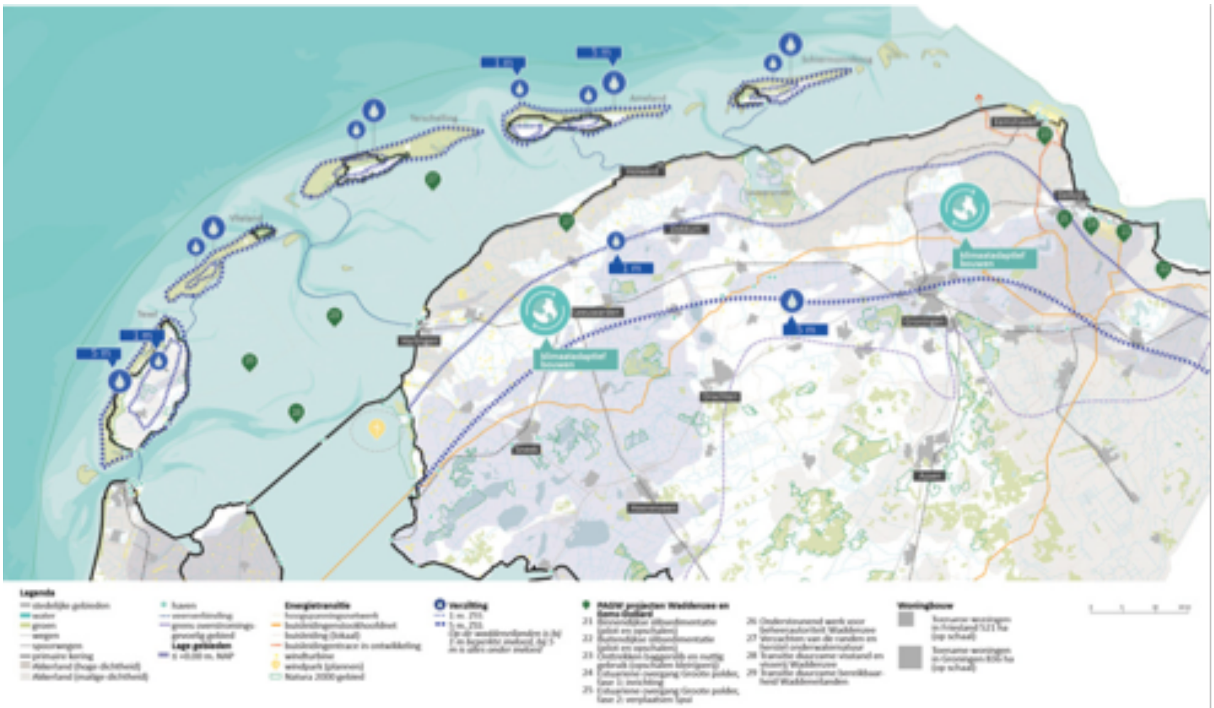


Figure 32; Possible spatial developments in the Retreat strategy (Defacto, 2020)

In this adaptation strategy, the land use will be redirected to serve the characteristics and preconditions that the water system determines. In contrast to the strategy Protect the water system serves as the leading motive for spatial layout. This means concretely that the northern coast will be predominantly used as salt marshes to decrease the forces of the sea. Where first a high density of croplands dominated the landscape in the region, now salinization which due to the salt marshes flows farther inland, traditional crops will not be viable and other land uses have to be found.

5.2.2 Here and now

To determine the effect of SLR on broader welfare the same indicators used in the case study of RMDS are used. In this section, these indicators will be assigned values to use in the multi criteria analysis to determine the preferred adaptation option in the Frisian Wadden-coast region.

Environment

In the Environment dimension, an assessment of the effects of SLR and its adaptation options on the current perceived environment in the area is given. Due to sea level rise especially salinization and flooding might cause problems in the area. Agriculture, in its current form, will no longer be possible in the coastal areas of the region as put forward by Defacto (2020). This means that the land use will be open to change under all adaptation options. In Retreat the land use is likely to become more natural, as the building is restricted to further inland areas, due to inundation levels being high on the coast (see Figure 32). In the Protect scenario, however, due to the need for housing, space no longer used for agriculture will likely also be demanded to provide housing. However, this region is a region of population decline. The population decline until 2040 is expected to be an average of 7.5% (Ministerie van Algemene Zaken, 2019), which makes that even more room for nature can be expected.

However, when doing nothing agricultural areas slowly turn useless for traditional agriculture and other uses have to be found. In the area, 70% of the land is used by agriculture and only 5% for forest and nature area (see Table 21). As such due to the response to the effects of sea level rise, environmental quality in the area might increase significantly. In the area, saline farming will be an option to cope with the salinization too. In de Vries et al. (2021) the baseline for the problem of salinization in agriculture in Friesland is set. In Te Winkel et al. (2021), the market potential and practical feasibility in the Wadden Sea region is analysed. It is noted that new cultivation techniques and as such large investments are required. Also, not every crop and variety can be grown everywhere. As this is one of the first researches addressing salinization in the area, no numbers are put forward, but the results of market potential feasibility and scale are promising (see Figure 33).

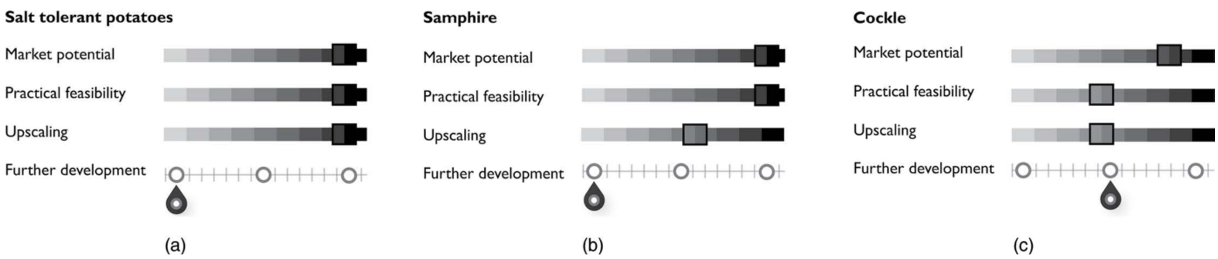


Figure 33; Potential in terms of different criteria for salt-tolerant potatoes (a), samphire (b), and cockles (c) (te Winkel et al., 2021)

These promising initiatives give an insight into the future potential for (saline) agriculture in the area. Therefore, the assumption of a promising but conservative 30% of the current farmlands to be converted into saline farming lands. This means that 21% of the current land use will be agriculture. The rest of the 70% of agricultural land use will go to either forest and nature or built area, depending on the adaptation strategy.

In the SLR scenario, when no adaptation strategy is used, the lost agriculture area will go to nature, as this is the least effort option. Then the share of forest and nature will rise with 49 percentage points, to 54%.

In the Retreat scenario, the same level of increase is expected. Retreating follows the dynamics of the water system and nature, therefore nature will obtain a larger share in the land use of 54%. This also follows the reasoning of Barry (1997) in Hickey & Salas (1995): 'Without levees, even a great flood...meant only a gradual and gentle rising and spreading of water. But if a levee towering as high as a four-story building gave way, the river could explode upon the land with the power and suddenness of a dam bursting'. Meaning that nature will be preserved more in the Retreat scenario than the status quo and the Protect scenarios.

In the Protect scenario, more land use can be assigned to the buildable area. The need for housing in the whole of the Netherlands requires also Friesland to take up some new housing projects. In Defacto (2020) a number of 34,000 new houses for the North of the Netherlands is mentioned. However, for the municipalities in the Frisian Wadden-coast in particular the Woningbouwkaart provides a maximum of 3000 houses, where the population decline of 7.5% is assumed to be already considered (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2021). On a housing stock of 28,599, this is an increase of about 10%. This means that also the built area likely increases by 10%. Although this might sound like a lot, in reality, the share of the built area only is 3%, yielding a built area share of 3,3%. Therefore, the Protect strategy will have a share of forest and nature of 72.7%, consisting of waters, recreational areas and forest and nature. Converting these percentages into scores gives values of 0.33 for the status quo, 1 for the SLR and Retreat scenarios and 0.996 for the Protect scenario.

Table 21; Proposed land-use shares in the Frisian Wadden-coast adaptation scenarios

Land-use	Status quo	SLR	Retreat	Protect
Traffic area	2%	2%	2%	2%
Built area	3%	3%	3%	3.3%
Semi-built area	0%	0%	0%	0%
Recreational area	1%	1%	1%	1%
Agriculture	70%	21%	21%	21%
Forest and nature	5%	54%	54%	53.7%
Backwater	2%	2%	2%	2%
Open water	16%	16%	16%	16%
Percentage nature	24%	73%	73%	72.7%
Score	**0.33**	**1**	**1**	**0.996**

Safety

In the previous case study, the expected increase in fatalities in the province of Zuid-Holland was used to find the relative number of deaths for each adaptation scenario. For the region of Frisian Wadden-coast, this expected increase based on population growth and SLR is not available in the literature. However, another method can be easily employed to obtain the increase or decrease in fatalities in the scenarios in Frisian Wadden-coast. By using the same number as in RMDS, but modifying them to suit the populational and risk changes in the Frisian Wadden-coast area, we can fill in Table 22 the same way as Table 11.

In the status quo, the Frisian Wadden-coast is protected by a dike trajectory. This dike trajectory currently has a flood probability of 1/3000 years, whereas the flood probability in the region of RMDS is lower with trajectory probabilities ranging between 1/3000 and 1/100000 (Waterveiligheidsportaal, 2021). Also, for the Frisian Wadden-coast, the by-law regulated individual risk is set at 1/100,000 per year to die from a flood. However, due to SLR this risk increases. It is assumed that again, this risk is based on population growth and increased probability of flooding. In the case of SLR in the Frisian Wadden-coast however, population growth is expected to be negative, averaged at 7,5% population decline (Ministerie van Algemene Zaken, 2019). Besides this population decline, the increased probability of flooding effect of 20% from Maaskant et al. (2009) is applied yielding an increase of 11%.

In the Protect scenario, the increased probability effect of flooding is eliminated by the extra protection measures, to a risk level of 1/100,000 per year (Rijkswaterstaat & STOWA, 2017). This means that no extra or less risk than the status quo is applied. Furthermore, population decline does not matter here, as previously it was argued that in the Protect scenario, the level of risk is decreased only to a level of 1/100,000 per year. That means that the Protect scenario obtains the same relative deaths as in the status quo.

In the Retreat scenario in the region of RMDS, only the affected areas in the region were expected to increase their private mitigation, either by moving out or by additional safety measures. However, in the Frisian Wadden-coast the whole of the region is affected. This means that a level of 50% of the population, analogous with Katrina (The Data Center, 2016), will apply extra measures, additional to the public measures of decreasing flood probabilities, likewise as in RMDS. This follows the reasoning of Baan & Klijn (2004), where the levee effect is eliminated by the Retreat strategy and the crises effect makes sure that people are more aware of flooding. This yields a -40% change in relative deaths.

Table 22; Scoring table of Safety in the Frisian Wadden-coast

Column1	**Status quo**	**SLR**	**Retreat**	**Protect**
Population growth		-7.5%	-50%	-7.5%
Sea level rise		20%	20%	
Change	0%	11%	-40%	-8%
Relative deaths	1.00	1.11	0.60	0.93
Score	**0.6**	**0.54**	**1**	**0.65**

Material welfare

In the case of RMDS, the output from the research of Koks et al. (2014) and de Moel et al. (2013) were used to create estimates of GDP loss in the region. However, such research as previously used is not available for the region of the Frisian Wadden-coast. Therefore the percentual damages from the loss in GDP in the RMDS are adopted. However, first, some transformations are performed.

In the region of Frisian Wadden-coast, the level of export is significantly lower. Therefore, the indirect effects of EAD will likely be lower. The weighted trade degree of Zuid-Holland is 2489,67 as opposed to 284,94 in the Frisian Wadden-coast. This means that the indirect effects of sea level rise on in % GDP loss in Frisian Wadden-coast are about 11.4% of RMDS, yielding an indirect GDP loss of 0,002% and a total GDP loss of 0,024%.

In a sea level rise scenario, these losses to GDP will be higher, as return rates of flooding increase. De Moel et al. (2013) show accurately for the RMDS region from the previous case study how EAD's increase in SLR scenarios. As there is no other research performed on the expected EAD increase in the Frisian Wadden-coast area, the same growth numbers are used. It is assumed that the increases in flood risk and damages in the RMDS region is equal to the increase in losses due to especially salinization in the Frisian Wadden-coast area.

In the case of protection, many of the functions of the region still can take place, except for one important, agriculture. As estimated before, saline farming can take up 30% of the losses in agriculture. Furthermore, the number of jobs per sector (see Table 24) shows that agriculture is not the only important sector in the region. Furthermore, protection increases the incentives to invest in the region and as such in the scenario of Protect less material welfare has to be given up than in the SLR scenario, but due to increased salinization reaching far inland, the status quo is better endowed. In terms of GDP loss, the assumption is made that it is in between the status quo and the SLR scenario at a loss of 0,03%.

In the retreat scenario, the problems of a decrease in economic activity remain. Not only agriculture is pushed back further inland, but many more activities follow the dynamics of the water. The region without further protection might not be livable, as also mentioned in Defacto (2020) and as such the current population decline will endure. This means that an even larger GDP/income effect is expected to occur. All in all, the effect will be larger than the losses in the SLR scenario, hence at least a value of 0.05% GDP loss is expected. To keep the same order of magnitude in the effects, a further step from 1 is taken to a level of 0.1% GDP loss, likewise as in RMDS.

Table 23; Scoring table Material welfare Frisian Wadden-coast

Scenario	**Status quo**	**Status quo in % GDP**	**SLR in % GDP**	**Retreat in % GDP**	**Protect in % GDP**
Factor SLR			212%		
Factor Indirect trade effect		11%	11%		
GDP Friesland	€ 19,840,000,000				
Direct damages	€ 4,364,800	0.022%	0.047%		
Indirect damages	€ 2,777,600	0.014%	0.003%		
New indirect damages		0.002%	0.0003%		
Total effect	€ 4,682,693	0.02%	0.05%	0.1%	0.04%
GDP scenarios		0.9998	0.9995	0.9990	0.9996
Score		**1**	**0.9998**	**0.9992**	**0.9999**

Jobs

In the Frisian Wadden-coast, the same study is carried out for the level of jobs in the four scenarios. Aside from Trade and Healthcare, Industry plays a significant role in the amount of jobs in the area. In contrast to the RMDS situation, the Agriculture sector is impacted across the entire region (the northern part of Rotterdam remained protected). As a result, the agriculture sector will suffer the greatest reduction in all scenarios. This is in line with Defacto's (2020) suggestion that agriculture should switch to saline agriculture in order to remain viable.

The second important affected sector is Industry, which is impacted through the losses of salinization and damages towards industry assets and accounts for 15% of jobs. In the SLR scenario, Industry in the area might suffer from the effects of salinization. Although, Industry is less severely affected than agriculture and thus a decrease of 2 is applied. For the Retreat case, not many changes occur and the effects of salinization endure. In the Protect scenario, the effects of salinization might endure, but a growth of the region can be expected due to increased incentive to invest, due to increased protection. Therefore, -1 point is applied.

In the second important affected sector Construction, which in the Frisian Wadden-coast region accounts for 5% of jobs, a negative effect can be expected due to SLR. Whereas in RMDS flood damages made for an increase, in the region of Frisian Wadden-coast the effect of salinization is more important which does not directly affect buildings. Furthermore, because there are considerably fewer people and buildings in the region, less repairs will be made. As a result of SLR, the region becomes less appealing to investors, and construction will drop by 2 points. In the Retreat scenario, this effect becomes even clearer as no more protection is being pursued at all, and a decrease of 3 points is applied. In the Protect scenario, however, an increase in building activities due to growth in the area will be expected. This will increase building labour demand by a large amount, especially when building programs will be pursued (see Table 24). This increase is temporary, but due to increased investment, a critical mass might be achieved that ensures investment from within. Therefore a permanent increase of 2 points is applied.

Flooding will have a significant impact on both trade and logistics in the Frisian Wadden-coast region. The region will be less appealing to trading and logistics enterprises to invest in due to the aforementioned possible supply chain interruptions. However, because trade is more clustered in the region, the number of jobs is affected more than in the RMDS region (0.82 instead of 0.33). As a result, a decrease of 3 is to be expected. In the Retreat scenario, like in the RMDS region, decreased investment incentives likely decrease the number of jobs in the region even further, hence a decrease of 4 is expected. In the Protect scenario, an increase in the number of jobs is projected as a result of increased investment in the region. However, opposed to the RMDS region which profits from agglomeration economies, the declining Frisian Wadden-coast does not. As a result, the increase will be less than the RMDS increase of 4 points. As a result, a 2 point bonus is granted in the Protect scenario.

The real estate sector isn't the most important in terms of jobs in the Frisian Wadden-coast regio, Real estate employs only 1% of the workforce. On the other hand, it is a sector that is particularly vulnerable to sea level rise. A reduction in house prices is projected by Bernstein et al. (2017). This will decrease investment in the sector of Real estate and, in turn, decrease the number of jobs. A significant drop in housing prices as a result of increased flood risk and decreased economic activity in the area will reduce Real Estate by at least two points, as was done in the RMDS region. However, in the Frisian Wadden-coast area, population decline already will decrease future demand for housing in the region and thus likely the decrease in jobs will be more severe. As a result, a 3-point reduction is applied. When implementing the Retreat strategy, a further fall in house investment in the Frisian Wadden-coast region will result in a further reduction in real estate jobs. Therefore, for Retreat a decrease of 4 points is applied. In the Protect case, however, an increase of housing units of approximately 10% (see Environment) is expected. Due to this increase in housing and the increase in economic activity due to investment incentivized by higher safety norms also an increase in the number of Real Estate jobs can be expected. Like in the RMDS region, an increase of 2 points is applied.

In the Retreat scenario, not only the sectors that are directly engaged with the effects of SLR will be hit, but also the sectors that suffer from the effects of migration, brain drain, and all other negative effects of the Retreat scenario. Therefore, all the other sectors that are mainly supportive of the sectors that are directly involved with the effects of SLR will be given a decrease of 1 point in the Retreat scenario. The sectors that are business supportive are Energy, Utilities, IT, Finance, Business services, Rental services, Public management, Education and Healthcare.

Table 24; Impacts on jobs in individual sectors in the Frisian Wadden-coast

Sector	Share (status quo)	Impact SLR	Retreat	Protect
Agriculture	3%	-5	-5	-5
Mining	1%			
Industry	15%	-2	-2	-1
Energy	0%		-1	
Utilities	0%		-1	
Construction	5%	-2	-3	3
Trade	18%	-3	-4	2
Logistics	5%	-3	-4	2
Hospitality	4%			
IT	1%		-1	
Finance	1%		-1	
Real Estate	1%	-3	-4	2
Business services	2%		-1	
Rental services	11%		-1	
Public management	4%		-1	
Education	6%		-1	
Healthcare	20%		-1	
Recreation	1%			
Other services	1%			
Total	100%	**-25%**	**-40%**	**7%**
Relative no. jobs	1.00	0.75	0.60	1.07
Score	**0.94**	**0.70**	**0.56**	**1.00**

Institutional quality

In the previous case study, it was explained how government trust might influence broader welfare and how it is affected by sea level rise and especially the options of adaptation. Likewise, as in the previous case study in the status quo, the trust in the government in the Frisian Wadden-coast region is assumed to be 1.

In the case of SLR, when doing nothing, trust in institutions will likely go down, however in contrast to the RMDS case, the level of perceived fairness will not be down. In the region RMDS there was a distinction between people in protected and unprotected areas. However, due to SLR in Frisian Wadden-coast, the whole area will eventually suffer the effects of SLR. Therefore, in the SLR scenario, the value where material loss and perceived fairness are switched on in the regression model is used. The value belonging to this is 2,516 – 0,189 + 0,795 = 3,122. This is a decrease of 6% and as such the value of 0.94 will be used in the MCA.

In the Retreat strategy, again it likely is perceived as unfair to the citizens of the region that they should leave, and no protection measures are taken. However, by retreating, the level of material loss due to flooding and increased salinization is kept at a minimum level. The probability of flooding and salinization damages is not decreased, but the damages themselves are. Therefore, the same value as for the Retreat scenario in RMDS is taken, which is 0.76.

In the Protect scenario, the high level of protection will increase the perception of fairness. However, again the Material loss will be switched on due to potential financial barriers to governments. However, still due to high Perceived fairness, it will be the highest among the three options together with SLR, and as such the value of 0.94 is awarded to Institutional quality in the Protect scenario in Frisian Wadden-coast.

Table 25; Scoring table for Institutional quality in Frisian Wadden-coast

	Status quo	**SLR**	**Retreat**	**Protect**
Constant	2.516	x	x	x
Perceived fairness	0.795	x		x
Material loss	-0.189	x		x
Maximum	3.311	3.122	2.516	3.122
Score	**1.00**	**0.94**	**0.76**	**0.94**

Housing

In the Frisian Wadden-coast area, the same analysis is performed as in the RMDS region. In the RMDS region, it was presumed that the level of inundation on the RMDS map showed a decrease in housing possibilities. For the region of Frisian Wadden-coast, it is easier to determine possible impacts on housing availability. As the entire region of the Frisian Wadden-coast in a SLR scenario will be less attractive to live, either because of flood risk or because of salinization, the impact scores of municipalities in the RMDS region that were quickly and deeply inundated can be adopted. Therefore, a decrease in the housing stock of 3 points can be expected in the SLR scenario. Furthermore, it can be expected that by not taking any stance against SLR, building in the area will likely continue. Therefore, the new housing stock will be used in the determination of the total scenario's housing stock, yielding a score of 0.40.

In the Retreat scenario likely even more housing is estranged by authorities to decrease the level of material loss to citizens. Furthermore, the old housing stock will be used, as in the Retreat scenario, no new investments will be pursued in the vulnerable region. The estrangement of housing will likely account for a larger loss than in the SLR scenario and therefore a decrease in 4 points can be expected. By applying the 4 point decrease to a lower housing stock where the building was not accepted, the scenario's housing stock delivers a score of 0.19.

In the Protect scenario, the function of housing is entirely safeguarded. The protection measures that are taken in the Protect scenario will decrease the level of flood risk and incentivize investment in the region, yielding jobs and housing to accommodate these jobs. In the Protect scenario also current plans for building new housing will be endorsed as safety is guaranteed by the protection measures. Therefore, again the new housing stock is used. This new housing stock will yield a score of 1 as this is the highest level of housing among the scenarios.

Table 26; Scoring table Housing in the Frisian Wadden-coast municipalities

Extra Houses Frisian Wadden-coast	3,000						
Municipality	**Housing stock Status quo**	**Extra houses**	**New housing stock**	**Share**	**Impact SLR**	**Retreat**	**Protect**
Harlingen	7,909	475	8,384	16%	-3	-4	6%
Noardeast-Fryslân	20,690	1,242	21,932	41%	-3	-4	6%
Waadhoeke	21,375	1,283	22,658	43%	-3	-4	6%
Total	49,974	3,000	52,974	100%	-60%	-80%	6%
Total scenarios	49,974				21,190	9,995	52,974
Score	**0.94**				**0.40**	**0.19**	**1.00**

5.2.3 Future generations

Economic capital

Although the region of the Frisian Wadden-coast does not offer an insight into their thoughts on the current level of economic resilience in the region like the city of Rotterdam does, there is evidence that does not observe large differences in resilience in the Dutch regions overall (Diodato & Weterings, 2014). However, the Frisian Social Planning agency names a low resilience on the job market (Fries Sociaal Planbureau, 2020). This, according to them, is due to very specific knowledge and skills that decrease intersectoral mobility. Furthermore, there are generally few jobs that are related to the skills in commuting distance. The Frisian agency itself mentions a solution to promote transitions in favour of the Frisians. This is by definition a development that serves the circular and ecological challenges that apply in the region and is in line with the concept of broader welfare (Fries Sociaal Planbureau, 2020). So, in other words, to increase resilience in the Frisian Wadden-coast area, based on the needs for resilience in Friesland as a whole, relatedness must be created to ensure jobs market resilience, but circular and ecological challenges should be considered. An example of this is where 'in certain sectors, natural conditions clearly influence earning capacity. Think, for example, of desiccation and salinization problems in the agricultural business in the north of the province'.

In the region, water technology is the specialization in terms of R&D (European Commission, 2018a). To retain relatedness in the region while still serving nature and circular/ecological challenges, Retreat might be the best option. In the Retreat option, many of the learning effects that occur through adapting to the water might offer insights into the region's R&D (Thomsen et al., 2012). However, Protect could offer learning effects to the water technology sector as well, as, for example, hydroengineering is a necessity to Protect. But, the Protect option does not take into account the ecological implications that Friesland acknowledges as being important. As such in the scoring model for Economic capital, Protect will offer less to Economic capital and will obtain the value 'Medium', Retreat will obtain the value 'Good'. In the SLR scenario, without committing to a strategy of adaptation, the resilience will likely shrink, as relatedness will not be enhanced, and ecology will not be given more space. The level of resilience in the status quo, according to Diodato & Weterings (2014) and Fries Sociaal Planbureau (2020) is not at a 'Good' level yet and will need a strategy to become so. As such it will obtain 'Medium'.

Table 27; Scoring table Economic capital in Frisian Wadden-coast

	Status quo	**SLR**	**Retreat**	**Protect**
Resilience	Medium'	Bad'	Good'	Medium'
Score	**0.5**	**0**	**1**	**0.5**

Natural capital

In the RMDS region, Brouwer & van Ek (2004) showed a comparison between the scenarios Protect and Retreat in their contribution to nature conservation policies, which was used to obtain the effect of the two options on Natural capital. However now, an analysis from Timmerman et al. (2021) will be used to obtain these results for Frisian Wadden-coast.

Timmerman et al. (2021) analyse two scenarios, the 'Open + dynamic' strategy, which is in line with the Retreat scenario, and the 'closed' scenario, which entails making the Wadden Sea fresh. As such only the 'Open + dynamic' strategy can be used, further referred to as Retreat.

Using this Retreat strategy in the Wadden area considers the removal of the existing flood defences on the Frisian Wadden-coast. This strategy will lead to an inland shift of the Wadden system. Along with this change, the current population and agriculture in the area have to give way and should move to higher grounds. But 'The natural dynamics of the WS, such as the landward roll-over mechanism of the barrier islands and the inland migration of salt marshes, will be restored'. The 'open + dynamic' strategy will enable the Wadden-sea to expand inland, while the current Wadden Sea will drown under future scenarios. The disappearance of intertidal areas and salt marshes will result in a loss of food and habitat availability for migratory birds. By allowing for inland migration of the sea these ecotopes will not disappear. For the Natural capital in the area, this might thus be a 'sustainable long-term solution to reduce future risk for coastal communities and ecosystems'. Therefore, Retreat will obtain the highest value. As for this dimension, it is particularly hard to appraise nature and no numbers are mentioned in Timmerman et al. (2021), the Natural capital will again follow the 3 step scale of ‘Bad’, ‘Medium’, ‘Good’. For Retreat this will mean ‘Good’.

On the other scenarios, SLR and Protect, Timmerman et al. (2021) offer the insight of ‘coastal squeeze’. Dikes make it impossible for the current system to retreat inland, and therefore ecotopes of the Wadden Sea will drown. But, when protecting, nature behind the dikes will likely be given more space. However, the first natural area in Friesland behind the dikes is the ‘Noardlike Fryske Wâlden’ and lies much farther inland than at the coast (see Figure 34) and no further natural areas are reported at the north-coast of Friesland (see Figure 35). Along with the absence of nature behind the dikes in the reasoning of Timmerman et al. (2021), the Protect will receive a lower value in Natural capital than the Retreat option. As such the Protect option will obtain ‘Bad’.

In the scenario where no adaptation strategy is used, the SLR scenario, a midway between the Retreat and Protect is assumed, as dikes may break with sufficient SLR allowing the seas to migrate inwards. As such the value ‘Medium’ is given. In the status quo, it is assumed that the Natural capital, with the undrowned Wadden Sea, is at a ‘Good’ level.

Table 28; Scoring table Natural capital in Frisian Wadden-coast

	Status quo	SLR	Retreat	Protect
Natural capital	Good'	Medium'	Good'	Bad'
Score	**1**	**0.5**	**1**	**0**

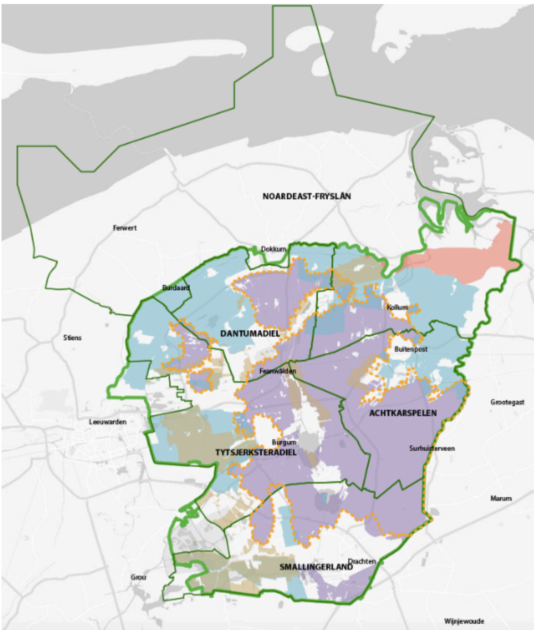


Figure 34; Noardlike Fryske Wâlden

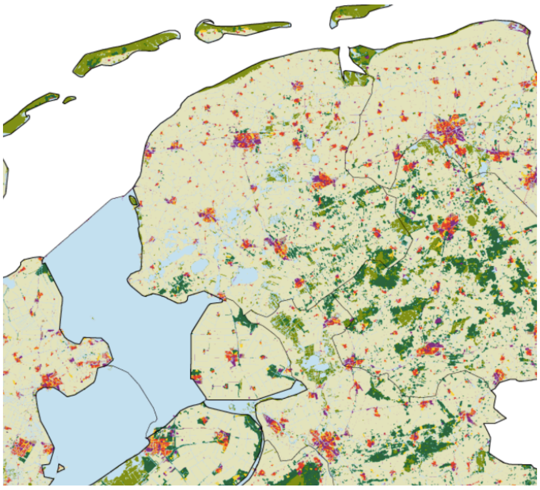


Figure 35; Land use map of the Friesland (adapted from Compendium voor de Leefomgeving, 2020)

Human capital

In the status quo, already the value of human capital in the Frisian Wadden-coast region is not as high as in the RMDS region. As previously put forward by the Frisian social planning agency (Fries Sociaal Planbureau, 2020), the resilience of the Frisian job market is low. In contrast to the reasons for leaving the RMDS region, where there is an abundance of economic activity and high relatedness and thus safety is a more important factor, in the region of Frisian Wadden-coast the absence of jobs might be one of the main reasons to leave the area. This is in history has been one of the main reasons for people to out-migrate the region too. The fertile clay soil in the north of the Netherlands has seen a decrease in value due to the modernization and marginalization of agriculture, while the peripheral location still causes barriers for the settlement of business and population (Hoogeboom, 2014).

As there are no numbers known for how Human capital is affected in the Frisian Wadden-coast an alternative scoring method will be used. The assumption that 'people follow jobs' can be disputed, as the results on the causality of this claim are highly divergent (Hoogstra et al., 2017). But it does offer support in attaching the values to Human capital in the three different scenarios. The scores of the Jobs dimension can likely be used to explain Human capital too. In the status quo, a value of 0.94 was used, not the highest in ranking, which is in line with Hoogeboom's (2014) story.

In future scenarios where the effects of SLR will further increase this lack of jobs it means that to sustain a livelihood in the area, workers have to either commute further or move to areas with jobs. This means that in a SLR scenario, there will be a decrease in Human capital. This is also seen in the score of Jobs, which obtained 0.70, a decrease from the status quo.

In Retreat, Jobs had a value of 0.56 showing the lowest level of employment opportunities. This is in line with the thought that further withdrawal of investment in the region will cause a further decrease of Human capital, as the region will become even less attractive to workers.

In the Protect scenario, the status quo will likely continue, but besides the phasing out of agriculture new investment in protective measures, and for example, the build of the new high-speed rail track to the north might induce attractiveness for companies and people to move into the newly protected area (Provincie Groningen, 2021). Therefore, when protecting a further boost will be given to the region and Human capital will flow increasingly to Friesland and the Frisian Wadden-coast. Thus, Protect shows the most promising potential to Human capital in the region and as such receives a 1, the value that was also used for Jobs.

Table 29; Scoring table Human capital in Frisian Wadden-coast

	Status quo	SLR	Retreat	Protect
Jobs score	0.94	0.7	0.56	1
Human capital score	**0.94**	**0.7**	**0.56**	**1**

5.1.4 Results Frisian Wadden-coast

In this section, the outcomes of the MCA in the Frisian Wadden-coast is given. The results of the MCA are shown in Table 30. In the MCA, the status quo again scored the highest with a score of 6.1. The score of the SLR scenario is the lowest of the four; 4.9. The two Adaptation strategies highest and almost equally, with 6.04 for Retreat and 6.05 for Protect. This means that Protect with a small margin is the preferred option of adaptation to SLR in the Frisian Wadden-coast region.

Table 30; Results of the MCA for Frisian Wadden-coast

Dimension	Status quo	SLR	Retreat	Protect	Weights
Environment	0.33	1.00	1.00	0.996	0.92
Safety	0.60	0.54	1.00	0.65	0.92
Material welfare	1.0000	0.9998	0.9992	0.9999	0.86
Jobs	0.94	0.70	0.56	1.00	0.84
Institutional quality	1.00	0.94	0.76	0.94	0.67
Housing	0.94	0.40	0.19	1.00	0.92
Economic capital	0.50	0.00	1.00	0.50	0.855
Natural capital	1.00	0.50	1.00	0.00	0.855
Human capital	0.94	0.70	0.56	1.00	0.855
Score	**6.1**	**4.9**	**6.04**	**6.05**	AVG = 0.855

In the Frisian Wadden-coast Protect was the preferred adaptation strategy. Again, Protect scored high on the dimensions Jobs, Housing and Human capital. For jobs especially the expectance of growth of the region due to increased incentives to invest in protection, in the sectors Construction, Trade, Logistics and Real estate make the difference. The difference in the relative number of jobs in the region is however much smaller. In the RMDS region, there was a 0.58 difference between the Protect and the Retreat option, opposed to only 0.47 in the Frisian Wadden-coast. This is likely since Industry is a larger sector in Frisian Wadden-coast, which is a sector that is hit hard by the measures proposed in Retreat. Also, Construction, Trade and Logistics obtain a positive value in Protect that is not as big as in RMDS, as Frisian Wadden-coast is not a centre of large logistical significance that RMDS is.

For Housing, again the Protect scenario does best, especially taken into consideration the low value of the Housing stock in Retreat. This especially low housing stock comes from the projected inundation of the entire region in Retreat as there are no cities that will still be attractive to live in are to be found in the region, opposed to RMDS, where Rotterdam remains liveable in the Retreat scenario. Therefore, Retreat offers far less Housing than Protect.

The third dimension that offers a good perspective in the Protect scenario is Human capital. Considering that the Protect region offers five times as much housing and almost twice as many jobs in the region the Protect scenario will offer people that are moving from elsewhere a living. The housing problem that is currently driving up housing prices through the roof will eventually cause people to find new centres of economic interest. As Retreat only makes moving to the Frisian Wadden-coast more difficult, the Protect option shows to be more future proof for Human capital.

The Retreat option, which has the same result score of 6.0 shows to be especially capable of offering Safety and Economic and Natural capital. Whereas in RMDS the difference between the Retreat and Protect option concerning Safety was not so big, with 6% more deaths in the Protect strategy, due to unawareness of flooding, in Frisian Wadden-coast a larger share of people that would be unprotected in the Retreat scenario, requiring them to move to safer places or put in place private mitigation against flood risk. This awareness of flooding, due to the crises effect, and the absence of the levee effect (Baan & Klijn, 2004), thus makes people die less frequently. Economic resilience was also shown to be higher in the Retreat scenario because of the learning effects of the Retreat option in the reasoning of Thomsen et al. (2012). But the difference in Economic resilience is less severe. This is due to the specialization of Friesland, in water technology, offering perspective in the Protect scenario too. In Natural capital, Retreat excels due to the empirical results of Timmerman et al. (2021) that stress the importance of inland migration of salt marshes which offer a sustainable long-term solution to reduce future risk for coastal communities and ecosystems.

When only a few dimensions of welfare would have been used, different strategies could have been preferred. Using only Material welfare would yield the preference for Protect, 0.9999 against 0.9992. Likewise, one could only look at the three highest weighted dimensions, Environment, Safety and Housing. This would yield the preferred strategy of Protect as well (see Table 31).

Table 31; Using only three important dimensions for MCA of RMDS

Dimension	**Status quo**	**SLR**	**Retreat**	**Protect**	**Weights**
Environment	0.33	1.00	1.00	0.996	0.92
Safety	0.60	0.54	1.00	0.65	0.92
Housing	0.94	0.40	0.19	1.00	0.92
Score	**1.7**	**1.8**	**2.0**	**2.4**	AVG = 0.92

6. Conclusion and Discussion

In this chapter, a conclusion of the findings in this research is given. Furthermore, a critical discussion is posed to note the implications of the research and discuss the limitations of the data used and the framework employed. First, a summary of the research is given. After this, the implications of these results will be discussed for the theory of SLR and adaptation. Furthermore, the practical implications of the results will be discussed. Lastly, the limitations of current research will be noted, and suggestions for future research will be given.

In the Netherlands, historically a battle against the water is fought. Due to SLR, this battle will continue. Adaptation towards SLR can help reduce its effects. In the Netherlands, Protect has been the method of choice. But when an adaptation tipping point is reached, the measures of Protect will be insufficient to remain at an equal level of welfare (Kwadijk et al., 2010). Therefore, a look forward is necessary. Retreat is another option to adapt to SLR. However, in the Netherlands, SLR has been disregarded in investments in housing causing a path dependency to Protect. To see if a different preferable adaptation strategy can be determined from using another definition of welfare, the concept of broader welfare is used to find the preferable adaptation strategy. To this end, the following research question was posed.

What broader welfare dimensions will be impacted by varying strategies of adaptation towards sea level rise in the Netherlands, and can a preferred strategy for the Dutch people be identified based on this?

In the literature review, the missing effects of SLR were pinpointed and a bottom-up approach was used to inventory the economic effects of SLR. A total of 71 direct and indirect effects of flood and coastal damages, salinization, and adaptation on broader welfare dimensions were found.

In the case studies that aimed to find a preferred adaptation strategy for SLR, a MCA was employed. The effects of SLR on broader welfare dimensions were analysed in different scenarios of adaptation for two regions in the Netherlands, Rijnmond-Drechtsteden and Frisian Wadden-coast. For the Rijnmond-Drechtsteden, given the weights and impacts used, the preferred strategy of adaptation was Retreat, with a score of 6.6 against 6.3 for Protect. In the Frisian Wadden-coast, the scores of Retreat and Protect lied close to each other, but the strategy of Protect was preferred with a score of 6.05 against 6.04 for Retreat.

The results show that, based on the dimensions of broader welfare and preferences from the Dutch people, a preferred strategy of adaptation towards sea level rise in the Netherlands can be determined. Also, it was shown that in both regions, when using all broader welfare dimensions a different result can be obtained than the use of only a narrow definition of welfare, for example by using only Material welfare or a combination of economic dimensions. The results show that in a region where economic activity is at a high level Retreat can still come out as the preferred option using the broader definition of welfare. This especially is due to the limit of adaptation (Kwadijk et al., 2010) and the effects of unlimited growth behind dikes (Husby et al., 2014), and the safe development paradox (Haer et al., 2020). In a region that, at first sight, offers less potential under SLR, Protect can as well come out as the preferred option. Namely this way, the Frisian Wadden-coast can profit from the consistent positive effects of immigration (IMF, 2020) due to increased protection, acting as a pull factor to immigrants.

The insights gathered in current research show, that for obtaining roughly the same level of Material welfare, in different adaptation methods, different sacrifices have to be made. For example, the Retreat strategy targets dimensions that are relevant to the environment and future generations. Protect, on the other hand, places a strong emphasis on economic elements as well as dimensions that are in the 'here and now'. This shows that it will remain especially difficult to find adaptation strategies that score high on both future & nature and present economic welfare. However, it also shows that if an adaptation strategy can capture the best of both worlds, broader welfare might even be higher than the two options considered. This could indicate that a strategy that lies somewhere in between the two might offer the highest broader welfare level. In practice, this has already been recognized. In the Netherlands, a combination of Protect and Retreat is already used in climate adaptation. An example is the 'Room for the river'-project (Hino et al., 2017) in combination with various protection measures in the Netherlands. Here, a mix of prevention and mitigation measures is used to cope with flooding.

Theoretical and practical implications

The results of the analysis performed contradict the results from Anthoff et al. (2010). They obtained that while the costs of sea-level rise increase with greater rise due to growing damage and protection costs, in a cost-benefit approach the protection of developed coastal areas dominates. However, when considering the effect of measures of the Protect strategy on broader welfare, future economic costs are also taken into account. As such adaptation tipping points will have to be considered making Protect less attractive in the long term (Kwadijk et al. 2010). Besides limits to adaptation, Anthoff et al. (2010) do not consider local contexts in their analysis, but from the perspective of current research's results even in the small Netherlands results can differ between regions.

However, when considering this locality, Brouwer & van Ek (2004) still found that Protect is the most cost-effective option in the RMDS region. They do, however, acknowledge that in the Retreat scenario, investments in land-use changes and floodplain restoration are economically beneficial in the long run if besides the avoided damage also the non-priced socio-economic benefits associated with these measures are taken into account. The benefits, that Brouwer & van Ek (2004) mention, are safety, the creation of new wildlife habitats, recreational and amenity values. These match the dimensions that were considered in this thesis and as such, the outcome for the RMDS region is in line with Brouwer & van Ek (2004).

To date, to the author's knowledge, no research has analysed the effects of sea level rise and adaptation methods in such an integral way. This thesis pioneered in setting the effects of sea level rise and adaptation into a broader welfare perspective. This has solved the problem that existed in the literature and society of which effects are to be considered when looking at adaptation options to sea level rise. In this thesis concepts such as path dependency (Haasnoot, van Aalst et al. 2019), social vulnerability (Kind et al., 2019) second-order effects (Koks et al. 2014), or ecological systems (Brouwer & van Ek, 2004) are integrated. It allows decision-makers to consider broader welfare dimensions from this contribution to go beyond the acceptance of narrow welfare policies. This research offers an extension to the existing literature and shows that many of the effects of sea level rise, such as salinization are seemingly undiscovered. Although to date adaptation has often been assumed to be only beneficial, it was also shown to have potential barriers and side effects, which could have an impact on the choice of whether to use adaptation and which strategy to use.

The practical implications of this study might include a trigger for policymakers to think about the effects of SLR and adaptation in a more systemic way, as many of the effects provided are linked. Also, this thesis could help in the identification of criteria for the analysis of adaptation methods. Especially, the thesis contributes to decision-makers' perspective the vast amount of consequences of SLR and adaptation that should be considered. Furthermore, offering a framework to analyse the effects of SLR and adaptation to broader welfare dimensions could help in the practice to determine a preferable adaptation strategy in their contexts.

When Retreat is the preferred adaptation option in other cases, the strategy must be implemented quickly. If this policy is adopted sooner rather than later, investments that will be required to be cleared in the case of SLR will be safeguarded. This way many costs for future generations will be prevented. In the case of the build of a new village in a low polder, today would be the day to act, as an ounce of prevention is worth a pound of cure.

Limitations

The current research has shown some interesting results and especially gives a basis for future SLR analyses that include also the broader welfare dimensions. However, these insights should be discussed in the light of some limitations that might get in the way of offering a fair comparison between the adaptation strategies that can be chosen to adapt to the effects of SLR.

First of all, to reach an analysis where every broader welfare dimension is represented, due to lack of contextual data assumptions had to be made, for example of the level of Material welfare loss. When considering the GDP loss of Covid-19 in the Netherlands with a value of 3,4% for example (CBS, 2021b), the order of magnitude of GDP effects (0.01-0.1%) seems very small. It could thus be that there is a much larger difference between scenarios in Material welfare, which could potentially change results. However, if these small differences would represent the real difference In Material welfare for the scenarios fairly well, these only have a very small effect on the outcome of the MCA. Because other dimensions have much larger differences between scenarios this small difference is overruled. This can for example make Natural capital which has large differences between scenarios, much more important for the choice of adaptation method than Material welfare. Based on the weight, however, these are equally important. In future research, this problem will have to be solved, and therefore a more critical weighting process of a composite indicator is necessary. For inspiration, one can consult the composition of the broader welfare indicator (BWI) in Rijpma et al. (2017).

However, as with many things in life, there is no one size fits all adaptation strategy to SLR. In this research, it was shown that even in the tiny country of the Netherlands two vastly different strategies of adaptation were preferable. Thus, it remains important to consider the preferences of the economic actors and stakeholders who have to adapt to SLR. Preferences for strategies can largely differ between actors, as some actors value some specifications of a method more than others. For example, companies in the Netherlands are more likely to value dimensions of broader welfare that increase the business climate, but citizens are more likely to value the abundance of green space in their neighbourhoods.

But also, future generations have different concerns than current generations. This shows for instance also the relevance of discounting in these kinds of analyses. The scope of this thesis did not include discounting, however, discounting gives a lower weight to future dimensions because the future is deemed less important to people than the present. Likewise, this thesis also does not engage with the phenomenon of diminishing returns in each of the dimensions. Considering diminishing returns to capital, for example, could change outcomes from the MCA from more emphasis on Retreat to more Protect, as Retreat generally scored higher in the capital dimensions.

Although a thorough review of the literature was applied to reach a set of effects that was as complete as could be reached in the process of this research, this thesis is unlikely to have encompassed the entirety of the effects of SLR on every potential broader welfare dimension. It thus could be that some effects were missed and some dimensions that have an impact on economic actor's broader welfare could have been added, especially when considering the subjectivity of the broader welfare dimensions. An example could be for example the effect of flooding on Subjective wellbeing, acknowledging the apparency that people do not like floods. Furthermore, this thesis is also likely to have suffered from measurement error. Some of the dimensions' measurement has been based only on empirical literature and expert knowledge found in the literature and the author's judgment. This was due to a lack of data on the subject and this subject, therefore, requires further research to reduce measurement error and increase the accuracy and precision of finding a preferred adaptation strategy for a certain region.

In addition, several assumptions mentioned in this study refer to sufficient conditions, when they are in fact, necessary conditions. The emergence of saline agriculture is one example. This is a necessary condition for agriculture to survive, as salinization will prevent other types of agriculture from functioning. However, the rise of saline agriculture by itself is not sufficient to ensure a future for agriculture. Farmers may pursue other businesses instead of saline agriculture. Because some of these assumptions were made in this study, the results should be interpreted with caution.

Lastly, in some dimensions in the MCA the mutual independence of preferences assumption was violated. Mutual independence of preferences is the case in which scores assigned to options under one dimension are not affected by the scores assigned under another dimension (Department for Communities and Local Government, 2009). This is for example in the Human capital dimension in the case of Frisian Wadden-coast. Because of a lack of data and literature that could support the assumption on Human capital it was assumed to be equal to the level of Jobs in the region. This however increases the possibility of double-counting and thus increases the value of the dimensions of Jobs and Human capital together in a scenario that is good for both. In this case, this may have caused the score of Protect to be higher in the Frisian Wadden-coast, as Protect is a scenario that is beneficial to Jobs and Human capital.

The limitations in this research have shown that a lot of work is still to be done in the causal determination of the optimal SLR adaptation strategy. Although, to include as many as possible direct and indirect effects and the broader welfare dimensions into the discussion of SLR effects and adaptation methods has been important. It fills the gap between the 'naïve' analysis of the effects of sea level rise in where a low level of detail is applied but indirect effects are allowed and the analysis for a local context where research disregards indirect effects. Furthermore, it shows that it is possible to integrate not only the narrow definition of welfare in SLR cost-benefit analyses but also the broader definition of welfare. This line of thought will help others in their steps towards an integral analysis of SLR and adaptation and its effects.

Suggestions for future research

In future research, explorations towards the causality of the effects that were proposed in this thesis are required. This will help in enhancing the precision and reliability of this framework. Furthermore, besides getting the effects right, more research on the weights used in this thesis is required. As mentioned, weights could differ largely between economic actors, and as such for each actor a different ideal adaptation strategy could exist.

Besides, in future research, it would be interesting to look into the broader welfare effects of the adaptation method Accommodate as well. But first, concrete consequences of adaptation strategies' measures have to be made. To increase the precision of estimating the economic effects there must be no doubt in, for example, the number of planned houses in a certain strategy. Suggestions for future research also include the quantification of the effects mentioned in this thesis and the concretization of adaptation strategies in different contexts in the Netherlands.

Lastly, recommendations to other lines of research could be to employ the broader dimensions of welfare in analyses. An example of this could be the problems in the Netherlands with the restriction of emission of nitrogen compounds, which are currently limiting agriculture, but on the other side of the coin help Natura 2000 habitats (Ministerie van Landbouw, Natuur en Voedselkwaliteit, 2021). Again here a broader welfare perspective would be helpful to explore, as there is are aspects that are of importance to future generations and current costs involved.

The main conclusion of this thesis is that a preferred strategy of adaptation to sea level rise can be identified using the effects of sea level rise and adaptation on the dimensions of broader welfare in the Netherlands in two different contexts. Using only a narrow definition of welfare shows to result in other adaptation strategies. The preferred strategy depends additionally on the context and preferences that economic actors may have for the dimensions of broader welfare. Future research may fill the gap in knowledge about the preferences of broader welfare dimensions and how to causally quantify the effects of sea level rise on dimensions of broader welfare.

9. References

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