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A comprehensive Analysis of Building Blocks for Climate Resilience

A development of impact analysis strategies for mitigation Strategies in the Netherlands

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Summary

This paper tackles the pressing issue of rising sea levels in the Netherlands, a consequence of ongoing climate change that poses severe risks to the country's future. The study centers on three strategic responses: seawards, protect, and moving along, as outlined by the "space for sea-level rise " project. These strategies aim to mitigate the impacts of sea-level rise and ensure the long-term safety and sustainability of the Netherlands' unique landscape. However, a significant challenge lies in understanding the full scope of both direct and indirect impacts these strategies may have on society and land use. To address this, the paper develops a comprehensive methodology for assessing these impacts, which is subsequently tested through a detailed case study. The outcomes of this study are intended to inform and guide the development of long-term climate adaptation strategies for the Netherlands.

The study begins with an in-depth examination of the factors currently shaping the Netherlands' future, considering both climate change and demographic trends. The climatological background section underscores the increasing vulnerability of the Netherlands to climate change, primarily due to rising global CO_2 emissions, which reached 40.6 Gt in 2022, leading to a CO_2 concentration of 418 ppm. This surge in greenhouse gases intensifies the enhanced greenhouse effect, trapping more heat and causing global temperatures to rise. For the Netherlands, this has dire implications, particularly in terms of sea level rise and land subsidence. The melting of Arctic ice sheets is a critical concern, as it could lead to a sea-level rise of up to 3 meters. Although the exact timing of such an event is uncertain, the potential consequences are so severe that it is imperative for the Netherlands to prepare for even the most extreme scenarios.

In addition to the threat of rising sea levels, the Netherlands must contend with other climate-related challenges, including increased saline intrusion along its coastline, particularly with a projected sea-level rise of 2 to 5 meters. Climate models for the Netherlands predict wetter springs, autumns, and winters, coupled with drier summers, a pattern attributable to the country's position between a drying Mediterranean and a wetter Scandinavia. These shifts in precipitation patterns are expected to significantly impact annual water availability and seasonal distribution, posing further challenges for water management and land use planning.

Simultaneously, the Netherlands is undergoing significant demographic changes that further complicate its response to climate change. The population is expected to grow to around 20.5 million by 2070, with the majority of this growth concentrated in urban areas, particularly in the Randstad region—a highly urbanized area that is largely below sea level and thus particularly vulnerable to coastal flooding. Another demographic trend of concern is the aging population, with a significant increase in the proportion of people over 65 expected in the coming decades. This demographic shift increases the population's vulnerability to disasters such as flooding, as older populations are generally less mobile and more susceptible to health complications during extreme events. The combination of urbanization and an aging population in high-risk areas amplifies the overall risk, underscoring the necessity for proactive and adaptive planning measures.

The primary objective of this project is to develop a methodology that can comprehensively assess all direct and indirect impacts associated with the implementation of one of these long-term strategies. This involves determining the extent to which these impacts can be qualified, quantified, and monetized. The methodology is designed to build upon existing impact analysis methods, incorporating cross-disciplinary techniques to better understand the potential outcomes of various policy decisions. This approach aligns with the work of Wiles et al. (2013), who highlighted that methodological advancements often stem from the adaptation of established methods, cross-disciplinary transfers, and technological innovations.

The impact analysis methodology developed in this study is structured around four main steps. The first step involves the spatial identification of alternatives, which lays the foundation for understanding the potential impacts of different policy measures. This step leverages spatial data to model the effects of these measures on land use and climate change, drawing on techniques proven effective in projecting climate change impacts at high resolutions across various scenarios. The second step compiles a list of potential direct and indirect impacts through an extensive literature review, with Environmental Impact Assessments (EIA) serving as the primary tool for this purpose. EIAs provide a framework for predicting the environmental effects of proposed projects or policies and are instrumental in identifying relevant impacts through cause-and-effect analysis. The third step focuses on impact assessment and monetization, applying cost-benefit analysis principles to evaluate the economic implications of environmental impacts. The final step tests the methodology through a case study in Holwerd, Friesland, allowing for an in-depth exploration of the methodology's application in a real-world context.

The impact analysis categorizes the effects of these strategies into six key areas: natural capital, living environment, social capital, heritage, reachability, and economic factors. This categorization helps to prevent the double counting of impacts by cross-referencing and systematically interconnecting these categories, ensuring that each impact is only counted once. The final step in the methodology involves qualifying, quantifying, and monetizing these impacts, providing policymakers with a clear, structured approach to assessing the potential outcomes of different strategies.

The Holwerd case study applies this methodology to the "moving along" strategy, examining the potential impacts by the year 2050. In the null alternative scenario, the region is expected to experience minimal land use changes due to climate change, with salinization affecting only a small part of the area. However, in the impact scenario, significant land use changes are anticipated, particularly as a result of the "Holwerd aan Zee" project, which envisions transforming agricultural plots and infrastructure into nature reserves and recreational areas. This transformation is expected to have both positive and negative impacts on various forms of capital, including natural, social, and heritage.

The impact analysis reveals that the creation of new natural areas could enhance biodiversity but at the expense of agricultural production. The shift from agriculture to nature-focused land use may also reduce traditional farming jobs, although it could create new opportunities in tourism and conservation. The project could impact freshwater availability due to increased salinization and may also affect the region's cultural heritage by displacing traditional farming practices. However, the transformation might improve the region's attractiveness as a tourist destination, enhancing its international reachability and economic prospects.

Several methodological considerations are identified through the case study, including the need to expand spatial analysis to include adjacent areas, better analyse synergies and antagonisms between project components, incorporate a discount rate for evaluating future costs and benefits, and add a stakeholder analysis to ensure that the perspectives of different groups affected by the project are considered. These refinements are essential for improving the accuracy and reliability of impact assessments, ensuring that the methodology can be effectively applied to a broader range of cases.

The conclusion drawn from this case study is that it is indeed feasible to make informed assumptions about the future impacts of policies intended for the distant future. This capability allows policymakers to more confidently plan precautionary measures, such as land reservations, for long-term policy decisions. However, caution is necessary due to the high spatial variability in climate and demographic changes, which can affect the accuracy of these predictions. While it is impossible to completely eliminate uncertainties in future impact predictions, they can be minimized by working on a small spatial scale and utilizing high-quality, localized data. The methodology applied in this case study has proven effective in using current climatological data to make accurate assumptions about future land use changes in the region.

By applying common impact analysis methods to these projected scenarios, policymakers can estimate the potential direct and indirect effects of future policies. These methods also allow for assumptions regarding the extent to which these impacts can be qualified, quantified, and monetized. However, further refinement of the methodology is needed, particularly to better understand and represent the synergies between different building blocks.
To optimize the " space for sea-level rise " project, it is recommended to consider solutions across multiple spatial scales and focus on the synergies between different building blocks. Implementing the suggested methodological improvements will help develop the most effective policies for protecting the Netherlands from long-term sea-level rise. The findings of this study provide valuable insights into the complexities of planning for climate change impacts and underscore the importance of a comprehensive, adaptive approach to safeguarding the future of the Netherlands

Samenvatting

Dit paper behandelt het dringende probleem van de stijgende zeespiegels in Nederland, een gevolg van de aanhoudende klimaatverandering die ernstige risico's vormt voor de toekomst van het land. De studie richt zich op drie strategische reacties—zeewaarts, beschermen, en meebewegen—zoals beschreven in het project "Ruimte voor Zeespiegelstijging". Deze strategieën zijn bedoeld om de impact van zeespiegelstijging te verminderen en de lange termijn veiligheid en duurzaamheid van het unieke landschap van Nederland te waarborgen. Een belangrijke uitdaging ligt echter in het begrijpen van de volledige omvang van zowel de directe als indirecte gevolgen die deze strategieën kunnen hebben op de samenleving en het landgebruik. Om deze uitdaging aan te pakken, ontwikkelt het paper een uitgebreide methodologie voor het beoordelen van deze gevolgen, die vervolgens wordt getest via een gedetailleerde casestudy. De resultaten van deze studie zijn bedoeld om de ontwikkeling van lange termijn klimaatadaptatiestrategieën voor Nederland te informeren en te begeleiden.

De studie begint met een diepgaand onderzoek naar de factoren die momenteel de toekomst van Nederland vormgeven, waarbij zowel klimaatverandering als demografische trends in overweging worden genomen. Het klimatologische achtergrondgedeelte benadrukt de toenemende kwetsbaarheid van Nederland voor klimaatverandering, voornamelijk als gevolg van stijgende wereldwijde CO_2-uitstoot, die in 2022 40,6 Gt bereikte, wat leidde tot een CO_2-concentratie van 418 ppm. Deze toename van broeikasgassen versterkt het versterkte broeikaseffect, waardoor meer warmte wordt vastgehouden en de wereldwijde temperaturen stijgen. Voor Nederland heeft dit ernstige gevolgen, met name in termen van zeespiegelstijging en bodemdaling. Het smelten van de Arctische ijskappen is een grote zorg, omdat het kan leiden tot een zeespiegelstijging van maximaal 3 meter. Hoewel de exacte timing van een dergelijke gebeurtenis onzeker is, zijn de mogelijke gevolgen zo ernstig dat Nederland zich moet voorbereiden op zelfs de meest extreme scenario's.

Naast de dreiging van stijgende zeespiegels moet Nederland ook andere klimaat gerelateerde uitdagingen het hoofd bieden, waaronder een toenemende zoute invloed langs de kustlijn, vooral bij een verwachte zeespiegelstijging van 2 tot 5 meter. Klimaatmodellen voor Nederland voorspellen nattere lentes, herfst- en winterperiodes, gecombineerd met drogere zomers, een patroon dat te wijten is aan de positie van het land tussen een uitdrogend Middellandse Zeegebied en een natter Scandinavië. Deze verschuivingen in neerslagpatronen zullen naar verwachting een significante impact hebben op de jaarlijkse beschikbaarheid van water en de seizoensgebonden distributie, wat verdere uitdagingen oplevert voor waterbeheer en ruimtelijke ordening. Tegelijkertijd ondergaat Nederland ingrijpende demografische veranderingen die de reactie op klimaatverandering verder compliceren. De bevolking zal naar verwachting groeien tot ongeveer 20,5 miljoen in 2070, waarbij het grootste deel van deze groei zich concentreert in stedelijke gebieden, met name in de Randstad—een sterk verstedelijkt gebied dat grotendeels onder zeeniveau ligt en dus bijzonder kwetsbaar is voor overstromingen. Een andere demografische trend van zorg is de vergrijzing van de bevolking, met een aanzienlijke toename van het aantal mensen boven de 65 jaar in de komende decennia. Deze demografische verschuiving vergroot de kwetsbaarheid van de bevolking voor rampen zoals overstromingen, aangezien oudere bevolkingsgroepen over het algemeen minder mobiel zijn en meer vatbaar voor gezondheidscomplicaties tijdens extreme gebeurtenissen. De combinatie van verstedelijking en vergrijzing in risicogebieden versterkt het algemene risico, wat de noodzaak benadrukt van proactieve en adaptieve planningsmaatregelen.

Als reactie op deze dubbele uitdagingen van klimaatverandering en demografische verschuivingen, evalueert het paper twee belangrijke strategieën: "Beschermen" en "Zeewaarts". De "Beschermen"-strategie richt zich op het versterken van bestaande waterveiligheidsmaatregelen, vooral in kwetsbare gebieden zoals het Rijn-Maas estuarium en de zuidwestelijke deltawateren. Deze strategie is verder onderverdeeld in vier benaderingen: het handhaven van een gesloten zeefront met vaste of stijgende waterstanden, en het gebruik van afsluitbare zeefronten met huidige of aangepaste stroomverdelingen. Elke benadering streeft ernaar een balans te vinden tussen de noodzaak van bescherming en de uitdagingen die worden veroorzaakt door de stijgende zeespiegel en toenemende rivierafvoer, waarbij sterk wordt vertrouwd op infrastructuur zoals pompen, sluizen en dijken. Deze maatregelen zijn ontworpen om overstromingen te voorkomen en waterstanden te beheersen, waardoor de veiligheid van de bevolking en de integriteit van het land wordt gewaarborgd.

De "Zeewaarts"-strategie daarentegen stelt een meer radicale aanpak voor door de aanleg van een zeewaarts kustbassin voor de zuidwestelijke kust van Nederland. Dit bassin zou helpen om rivierafvoer en zeespiegelstijging te beheren door extra wateropslagcapaciteit te creëren en gebruik te maken van grootschalige pompsystemen. De strategie is ontworpen om schaalbaar te zijn, waardoor aanpassingen mogelijk zijn naarmate de zeespiegel blijft stijgen, en zo een langetermijnoplossing biedt voor waterveiligheidsuitdagingen. Door deze strategieën in detail te onderzoeken, legt het paper de basis voor het begrijpen van de complexe wisselwerking van factoren die beheerd moeten worden om Nederland te beschermen tegen de gevolgen van klimaatverandering.

Het primaire doel van dit project is het ontwikkelen van een methodologie die alle directe en indirecte effecten van de implementatie van een van deze langetermijnstrategieën uitgebreid kan beoordelen. Dit omvat het bepalen in hoeverre deze effecten kunnen worden gekwalificeerd, gekwantificeerd en gemonetariseerd. De methodologie is ontworpen om voort te bouwen op bestaande impactanalyse-methoden, waarbij cross-disciplinaire technieken worden geïntegreerd om de potentiële uitkomsten van verschillende beleidsbeslissingen beter te begrijpen. Deze benadering sluit aan bij het werk van Wiles et al. (2013), die benadrukten dat methodologische vooruitgang vaak voortkomt uit de aanpassing van bestaande methoden, cross-disciplinaire overdrachten en technologische innovaties.

De impactanalysemethodologie die in deze studie is ontwikkeld, is gestructureerd rond vier hoofd stappen. De eerste stap omvat de ruimtelijke identificatie van alternatieven, die de basis legt voor het begrijpen van de mogelijke gevolgen van verschillende beleidsmaatregelen. Deze stap maakt gebruik van ruimtelijke gegevens om de effecten van deze maatregelen op landgebruik en klimaatverandering te modelleren, met gebruik van technieken die effectief zijn gebleken bij het projecteren van klimaatveranderingseffecten op hoge resoluties in verschillende scenario's. De tweede stap verzamelt een lijst van mogelijke directe en indirecte effecten via een uitgebreide literatuurstudie, waarbij Milieueffectrapportages (MER) als belangrijkste instrument worden gebruikt voor dit doel. MER's bieden een kader voor het voorspellen van de milieueffecten van voorgestelde projecten of beleidsmaatregelen en zijn instrumenteel bij het identificeren van relevante effecten via oorzaak-en-gevolg-analyses. De derde stap richt zich op impactbeoordeling en monetaire waardering, waarbij principes van kosten-batenanalyse worden toegepast om de economische implicaties van milieueffecten te evalueren. De laatste stap test de methodologie via een casestudy in Holwerd, Friesland, waardoor de toepassing van de methodologie in een realistische context diepgaand wordt onderzocht.

De impactanalyse categoriseert de effecten van deze strategieën in zes hoofdgebieden: natuurlijk kapitaal, leefomgeving, sociaal kapitaal, erfgoed, bereikbaarheid en economische factoren. Deze categorisering helpt om het dubbel tellen van effecten te voorkomen door kruisverwijzingen en systematische verbindingen tussen deze categorieën, waardoor elk effect slechts één keer wordt geteld. De laatste stap in de methodologie omvat het kwalificeren, kwantificeren en monetaire waardering van deze effecten, waardoor beleidsmakers een duidelijk en gestructureerd proces krijgen om de potentiële uitkomsten van verschillende strategieën te beoordelen.
De Holwerd-casestudy past deze methodologie toe op de "meebewegen"-strategie, waarbij de mogelijke gevolgen voor het jaar 2050 worden onderzocht. In het nulalternatief scenario wordt verwacht dat de regio minimale veranderingen in landgebruik zal ondergaan als gevolg van klimaatverandering, waarbij verzilting slechts een klein deel van het gebied zal beïnvloeden. In het impactscenario daarentegen worden significante veranderingen in landgebruik verwacht, met name als gevolg van het project "Holwerd aan Zee", dat zich richt op het omvormen van landbouwpercelen en infrastructuur tot natuurreservaten en recreatiegebieden. Deze transformatie wordt verwacht zowel positieve als negatieve effecten te hebben op verschillende vormen van kapitaal, waaronder natuurlijk, sociaal en erfgoed.

De impactanalyse onthult dat de creatie van nieuwe natuurgebieden de biodiversiteit zou kunnen vergroten, maar ten koste van de landbouwproductie. De verschuiving van landbouw naar natuurgericht landgebruik kan ook traditionele landbouwbanen verminderen, hoewel het nieuwe kansen kan creëren in toerisme en natuurbehoud. Het project kan de beschikbaarheid van zoetwater beïnvloeden door toegenomen verzilting en kan ook het cultureel erfgoed van de regio beïnvloeden door traditionele landbouwpraktijken te verdringen. De transformatie zou echter de aantrekkelijkheid van de regio als toeristische bestemming kunnen verbeteren, wat de internationale bereikbaarheid en economische vooruitzichten zou kunnen versterken.

Door de casestudy worden verschillende methodologische overwegingen geïdentificeerd, waaronder de noodzaak om ruimtelijke analyse uit te breiden naar aangrenzende gebieden, de synergiën en antagonismen tussen projectcomponenten beter te analyseren, een discontovoet toe te passen voor het evalueren van toekomstige kosten en baten, en een stakeholdersanalyse toe te voegen om ervoor te zorgen dat de perspectieven van verschillende groepen die door het project worden beïnvloed, worden meegenomen. Deze verfijningen zijn essentieel voor het verbeteren van de nauwkeurigheid en betrouwbaarheid van impactbeoordelingen, zodat de methodologie effectief kan worden toegepast op een breder scala van gevallen.

De conclusie die uit deze casestudy wordt getrokken, is dat het inderdaad mogelijk is om goed geïnformeerde aannames te doen over de toekomstige impact van beleid dat gericht is op de verre toekomst. Deze mogelijkheid stelt beleidsmakers in staat om met meer vertrouwen voorzorgsmaatregelen te plannen, zoals landreserveringen, voor langetermijnbeleidsbeslissingen. Er is echter voorzichtigheid geboden vanwege de hoge ruimtelijke variabiliteit in klimaat- en demografische veranderingen, die de nauwkeurigheid van deze voorspellingen kan beïnvloeden. Hoewel het onmogelijk is om onzekerheden in toekomstige impactvoorspellingen volledig te elimineren, kunnen ze worden geminimaliseerd door op een kleine ruimtelijke schaal te werken en gebruik te maken van hoogwaardige, lokaal beschikbare gegevens. De in deze casestudy toegepaste methodologie heeft bewezen effectief te zijn bij het gebruik van huidige klimatologische gegevens om nauwkeurige aannames te doen over toekomstige veranderingen in landgebruik in de regio.

Door gangbare impactanalysemethoden toe te passen op deze geprojecteerde scenario's, kunnen beleidsmakers de mogelijke directe en indirecte effecten van toekomstig beleid inschatten. Deze methoden maken ook aannames mogelijk over de mate waarin deze effecten kunnen worden gekwalificeerd, gekwantificeerd en gemonetariseerd. Verdere verfijning van de methodologie is echter nodig, vooral om de synergiën tussen verschillende bouwstenen beter te begrijpen en te vertegenwoordigen.

Om het project "Ruimte voor de Zeespiegelstijging" te optimaliseren, wordt aanbevolen om oplossingen te overwegen op meerdere ruimtelijke schalen en te focussen op de synergiën tussen verschillende bouwstenen. Het implementeren van de voorgestelde methodologische verbeteringen zal helpen bij het ontwikkelen van de meest effectieve beleidsmaatregelen om Nederland te beschermen tegen lange termijn zeespiegelstijging. De bevindingen van deze studie bieden waardevolle inzichten in de complexiteit van het plannen voor klimaatveranderingseffecten en onderstrepen het belang van een uitgebreide, adaptieve benadering om de toekomst van Nederland te beschermen.

1 Introduction

Due to anthropogenic forcing, the climate has warmed at an unprecedented rate (IPCC, 2023). This warming has caused the melt of artic ice to occur, which has resulted in an increasing rise of the global sea levels (IPCC, 2023). This is a troubling development, especially for a country like the Netherlands that lies approximately 26% below sea level (Stolte et al., 2022). There is evidence suggesting that sea levels along the Dutch coast could potentially rise by up to five meters by the year 2200 (KNMI, 2023). For this reason, the Netherlands is looking for viable solutions to this extreme rise in sea level. These solutions are assessed in the "Ruimte voor zeespiegelstijging" project, which means space for sea-level rise in Dutch. In this project, three alternative strategies have been considered to protect the Netherlands from a rising sea level up to five meters. These different solutions are called "zeewaarts," "beschermen" & "meebewegen" (respectively seawards, protect & moving along) and vastly differ in how they protect the Netherlands from a rising sea level.

The project "space for sea-level rise" is part of a broader project called "Kennisprogramma zeespiegelstijging" (knowledge program sea level rise). In "knowledge program sea level rise" governments, businesses, knowledge institutions and civil society organizations are joining forces. They are studying the possible consequences of sea level rise for the Netherlands and exploring measures to prepare for the consequences.

Strategy "seawards" protects the Netherlands by creating a new levee ring around the coast of Zeeland (Deltaprogramma, 2023). This levee ring will cause a fresh/brackish lake to be created in front of the Netherlands. "Protect" is the most similar to the status quo (Deltaprogramma, 2023). Here, levees will continue to be strengthened to adapt to the rising sea levels. In the most extreme case of this measure all the river mouths will also be enclosed to shorten the distance of levees necessary to protect the Netherlands. With the strategy "moving along" the Netherlands allows the water to come more inland (Deltaprogramma, 2023). In this strategy a majority of Dutch society will adapt by moving to higher located regions in the Netherlands and there will be a significant change in the land use for the now flood prone regions. The three strategies contain so called building blocks; measures that could be implemented according to the guidelines of the strategy it belongs to. These building blocks exist of a wide range of measures. Some are shared between the three strategies, and others are highly specific for their respective strategy. In chapter 4 a more in-depth explanation of the strategies can be found.

Figure 1: the building block "building on poles".

(Ministerie van Infrastructuur en Waterstaat, 2024)

The initial three studies have focused solely on whether the three strategies can achieve the goal of safeguarding the Netherlands against a two and five-meter rise in sea levels. However, there's a significant gap in understanding of the direct and indirect impacts that these proposed strategies might have on Dutch society and land use. Crucial questions about how these measures will affect the immediate and broader surroundings of where they are implemented, as well as how they interact with each other, have not been analysed yet. Literature on this topic generally falls into two categories. The first category involves climate impact analysis, which focuses on the effects of climate change in specific areas. These studies do not, however, explore how various measures might further affect these areas. An example of this approach is the meta-analysis of the economic impacts of climate change conducted by Tol (2024).

The other type is that of the measure impact analysis. In these types of studies there has been looked at the impacts certain policy measures will have. Studies like Alves et al. (2020) have looked at the influence of certain policy decisions on a given region or on climate change itself.

The problem in this lies that there is no interaction between the two types of studies. For example, Briassoulis (2020) argues that there is a need to integrate various thinking methods in this type of analysis. This is supported by the fact that the impacts of climate change have far reaching consequences in the future. Certain measures that seem pointless now might be necessary to be implemented later due to climate related changes. It is crucial that it is studied how implementing a given policy might impact a given region that has been altered in the future due to climate change, allowing policymakers to effectively choose the best strategy.

To give policymakers accurate insight into the potential impacts that a far future policy might have, a sound method to identify, qualify, quantify and where possible monetize the effects needs to be developed. Sinden (2019). has shown that due to lack of data, agencies often times exclude data that could have been significant for the project simply because the data is limited in the degree in which it is monetizable. The methodology proposed in Robak et al. (2023) can assist in accounting for every impact. In Robak et al. (2023) impacts are described as so called “flows” where the “flow” goes from impact to impact to eventually gather every possible direct and indirect impact. This is beneficial as the impacts have to be attained for a wide array of different types of building blocks.

Additionally, there's a knowledge gap in the methodology for obtaining a comprehensive understanding of all the direct and indirect impacts of implementing future building blocks on various criteria. Developing, reviewing, and refining the methodology is crucial in the short term, as it could be applied to the " space for sea-level rise " project as a whole. In the long term, the developed methodology could serve as a framework for similar analyses in other projects.

The interdisciplinarity comes predominantly from two fields of science. The first of these is environmental sciences. This is as the methodology for analysing climate change needs to be sound. For this, a background knowledge of the climate sciences is required. The second field is that of economics. As the ultimate goal in this rapport is to qualify, quantify and monetise the given impacts, it is essential to guarantee that the economic part of the framework is sufficient. Part of this project will be that of the social sciences. This is because it is almost guaranteed that the impacts will also have an effect on the livelihoods of the people living in the afflicted regions.

1.1. Research objectives

The main objective of this study is to develop a methodology that will attain the direct and indirect impacts of implementing various measures. This methodology should be clear, concise, and replicable, as it potentially will be used to obtain all the direct and indirect influences for all of the building blocks that will be analysed in the “knowledge program sea level rise”.

This methodology will be tested through the use of a case study. Namely, by estimating the direct and indirect effects of implementing a given building block and where possible also the costs or benefits that implementing it will bring. Through this preliminary research it possible to gain insights whether the methodology is sound enough to be replicated and applied in other “long-term” policy implementation analyses and to be consistently used throughout the “knowledge program sea level rise” for the other building blocks.

1.2. Research questions

To achieve precise solutions to the issues outlined in the introduction, the following research question will be answered.

“How can the direct and indirect effects of implementing various building blocks for mitigating the effect of sea level rise in the Netherlands be systematically analysed, including their interactions with different sectors and ecosystem services, to inform long-term climate adaptation strategies?”

The answer to this question will be attained by answering the sub-questions shown below.

1. Is it possible to project the impacts of climate change on land-use in the Netherlands?
2. What are the potential direct and indirect effects of implementing the different building blocks in the various long-term strategies, on the future land-use in the Netherlands?
3. How do these building blocks interact with each other and with their surroundings, considering regional differences and spatial allocation?
4. How can the impacts be qualified, quantified and monetised of the various building blocks?
5. What further research is needed to address remaining knowledge gaps and uncertainties?

2 Background

This chapter examines the current and projected impacts of climate change and demographic shifts on the Netherlands. It provides a critical overview of the factors influencing the country's future, highlighting the urgent need for effective adaptation strategies. The final section of the chapter will offer context for the proposed strategies, Seaward and Protect, to better understand their relevance and application.

2.1. Climatological background

As stated in the introduction, the climate has been warming at an alarming rate due to the anthropogenic forcing of greenhouse gases (IPCC, 2023). Global CO_2 emissions have continued to rise, reaching an amount of 40.6 Gt in the year 2022 (Riahi et al., 2017 & Rogelj et al., 2018). This has amounted to a global CO_2 concentration of 418 ppm in the year 2022 (Riahi et al., 2017 & Rogelj et al., 2018).

The sun emits a wide spectrum of energy, with the majority concentrated in the visible and near-visible ranges. Visible light, spanning from 400 to 700 nm, accounts for 43% of total solar energy, while shorter wavelengths such as ultraviolet light, though making up only 7 to 8%, carry significant energy per photon. The remaining energy, roughly 49 - 50%, lies in longer wavelengths, including near and thermal infrared (Wang & Yu, 2023). CO_2 primarily interacts with longer wavelength energy, notably strengthening the greenhouse effect. This effect arises from the interplay between solar energy and greenhouse gases like CO_2 in Earth's atmosphere. These gases possess a molecular structure that enables them to absorb heat, subsequently reemitting it back towards the surface. This process prevents the heat from escaping into space, effectively warming the planet's surface (Darkwah et al., 2018).

The consequences of these rising emissions are increasingly evident in the Netherlands, where the combination of sea level rise and land subsidence poses significant risks to water safety (Deltares, 2023 & Erkens, 2021). Here another troubling development is occurring. Recent studies have shown that the artic ice sheets might be melting at an accelerated rate. Rignot et al. (2024) states that "*At that point, the bed elevation drops into the deeper Bentley Subglacial Trough, and the glacier retreat will accelerate and may not stop until the entire basin drains to sea. Subsequent to that, other marine-based parts of West Antarctica will collapse for a combined total sea level rise of 3 m*." However, there is for now limited understanding of how long it will before this glacier retreat reaches a threshold that causes this rapid sea level rise to occur. For this reason, it is of the utmost importance for the Netherlands to prepare for an extreme rise in sea level.

While the rising sea level is arguably the largest problem facing the Netherlands due to climate change, it is not the only one. For one, the rising sea level will cause an increase in saline intrusion along the entire Dutch coastline. The amount of intrusion will have increased with 120% with a rise of two meters and if the trend continues with 330% at five-meter rise (Delsman et al., 2022). According to KNMI (2023), another climatological consequence of climate change is the projection of wetter spring, autumn, and winter seasons, contrasted with drier summers. The reasoning for this is that the Netherlands is in a wide transition area between a drying Mediterranean and a wetter Scandinavia.

The KNMI has developed two extreme emissions scenarios that are possible in the Netherlands: 1) a wet scenario in which the first effect dominates, with winters becoming very wet and summers slightly dry and, 2) a dry scenario in which winters become slightly wet and summers dry out strongly. In general, the assumption can be made that the annual precipitation amounts in the future between -3% and +8% in 2100, with winters becoming wetter in any case and extreme summer showers increasing further (Kennisportaal Klimaatadaptatie, 2024). It is important to note that the droughts will predominantly take place land inward. Inland, the increase in temperature and potential evaporation is partly caused by climate change. With no increase in precipitation, this therefore means that inland areas are more likely to experience drought due to climate change (KNMI, 2020)

On the other hand, the increase in evaporation rate due to climate warming leads to a corresponding increase in precipitation, with a global average increase of 2% per degree of warming. However, in regions where precipitation occurs, such as during rainstorms, the increase in precipitation is much greater, at 7% per degree or more. This intensified rainfall leads to shorter but more intense precipitation events. This causes this dynamic of wetter autumns, winters & springs, and drier summers to occur (KNMI, 2019). Data from KNMI (2023) supports this. Here it is shown that that autumn will experience an increase of precipitation in the year 2150 of around 4%, winter of around 23%, spring of around 5% and summer a decrease in precipitation of around 31%.

2.2. Demographic developments

While the climate is changing there are also demographic changes occurring in the Netherlands. Many of these developments are worrisome as they regard the resiliency of a given region. For this reason, a brief overview of the predicted demographic change will be given.

The first and most notable is that of a continuation in population growth. It is predicted that by the year 2070 the Netherlands will have reached a population of around 20,5 million individuals (CBS Statline, 2023). This trend is in itself not that bad. However, this increase in population is not equally spread over the entirety of the Netherlands. The Netherlands has a high degree of urbanisation, sitting at around 93% (World Bank Open Data, 2018). Large concentrations of these urban cores are located in the west of the country (PBL & CBS, 2022). This region is known as the "Randstad" and lies predominantly below sea-level. In figure ... the predicted population growth per municipality is shown. In this figure a population shift westward is visible.

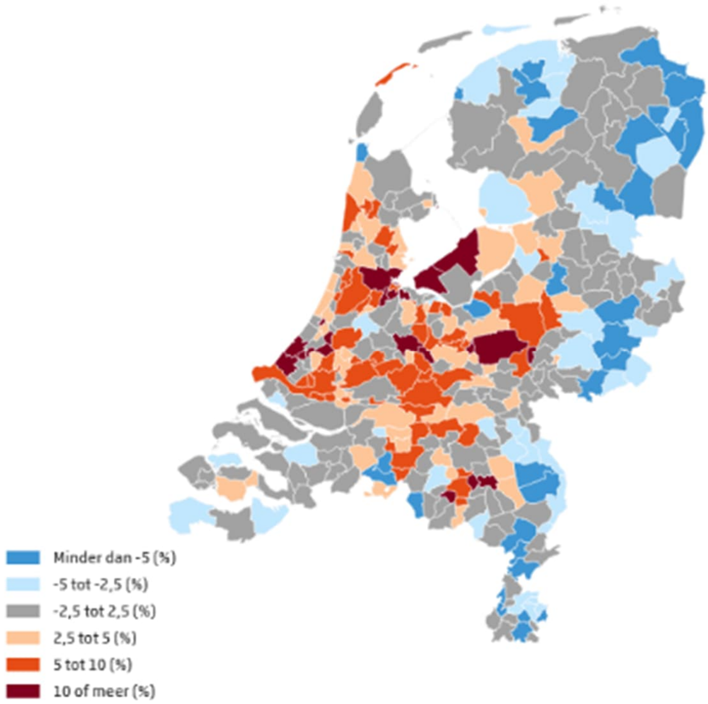

Figure 2: The degree of population growth (PBL & CBS, 2022)

Another troublesome development is that of an aging population. It is predicted that the amount of people above the age of 65 will continue to rise in the 21th century (PBL & CBS, 2022). The risk that a given area will have during a disaster is linked to the formula below.

Figure 3: The disaster risk equation (UNDRR, 2015)

The elderly are considered a vulnerable group (Phraknoi et al., 2023). Due to this, an increase in the amount of them will cause the risk of a sea level rise induced flood to increase.
In this equation it is also visible how the increased urbanisation in the west of the Netherlands will increase the total risk. This is so because the exposure will increase in the regions that are most at risk for coastal flooding.
For this reason, it is of the utmost importance to look ahead at the far future to best prepare for the potential risks that will come.

2.3. An overview of the various strategies

Before the case study, a brief overview is given for the potential impacts of the other two strategies (protect and seaward). This can be done for these strategies as they have a far more developed spatial aspect to them. Here the table discussed in the methodology will be filled in with only the plus minus method. The benefits of this are twofold. For one it gives further in the project clarity about what the possible impacts of the building blocks relating to "protect" and "seaward" could be. Secondly, potential advantages and disadvantages for this table could already by ascertained. This assists in making clearer assumptions about the soundness of the developed methodology.

2.3.1. Protect

The strategy “protect” predominantly focusses on the Rhine-Meuse estuary, the southwestern delta lakes, and rivers such as the Waal, Lek, and Meuse. Here the predominant strategy is to protect the Netherlands using small adaptations in the current water safety strategy. This is in stark contrast with the strategies of “move with” and “seawards” that are far more radical in their strategy of protecting the Netherlands from two- and five-meters sea-level rise. “protect” is subdivided in four different strategies. These sub strategies are:

- Strategy a1: Closed sea front with a fixed target level around NAP 0 m.
- Strategy a2: Closed sea front with a rising target level.
- Strategy b1: Lockable sea front combined with the current flow distribution.
- Strategy b2: Lockable sea front combined with an adjusted flow distribution.

2.3.1.1. A1: Closed sea front with a fixed target level of around NAP 0 M

Strategy A1 is characterized by a closed seaward front, maintaining the target water level inside around NAP through discharge outlets and additional pumps where necessary. The Westerschelde, Rijn-Maasmonding, and Zuidwestelijke Delta are closed off from the sea in this strategy, minimizing saltwater intrusion. The ARK/NZK system and the IJsselmeer are also enclosed. This way heightening the current river levees is avoided, preventing the loss of area outside of the levees.

This approach heavily relies on pumping capacity. River discharge is managed via pumps to prevent extreme water level rises during high river flows, with additional water storage in the delta. In the Zuidwestelijke Delta, a polder is created. Sea-to-inland navigation transfer will largely occur overland (reducing lock operations) or through smart lock designs to minimize saltwater intrusion during lock operations.

Extra buffers are established for freshwater supply, with one on the IJsselmeer and Markermeer and one in the Zuidwestelijke Delta. These buffers are filled in advance to ensure access to freshwater during dry periods, although the Zuidwestelijke Delta buffer may not be entirely fresh due to upward seepage. The permissible level rise for this buffer is chosen to minimize impact on areas outside the levees. Simultaneously, it's desirable for these buffers to be empty during high water events to avoid additional dike reinforcements.

Figure 4: an overview of strategy A1

(Ministerie van Infrastructuur en Waterstaat, 2024)

2.3.1.2. A2: Closed sea front with a rising target level

Strategy A2 involves maintaining a closed coastal defense system similar to strategy A1. However, there is one big difference. Instead of keeping the target water level in the Rhine-Meuse estuary and the Southwest Delta at current levels, it will rise with sea level. This is to enable more discharge via the use of sluice gates. This approach requires reinforcing levees and affects some areas outside the levees. Like in strategy A1, a polder will be created in the Southwest Delta, but the water level in this polder will rise along with sea level, allowing daily discharge of river flow through sluices. However, these sluices will close daily before the tide turns. During high river flow, water levels upstream rise, partly mitigated by storage and pumping. This puts significant pressure on areas outside the levees.

Since the Westerschelde, Rhine-Meuse estuary, and Southwest Delta are closed off from the sea, saltwater intrusion is minimal. The ARK/NZK system and the IJsselmeer will also be closed, maintaining current water levels (not rising with sea level as in the Southwest Delta). Sea-to-inland shipping will largely occur over land or through smart lock designs to minimize saltwater intrusion. Additional water buffers will be created for freshwater supply, including buffers in the IJsselmeer/Markermeer and the Southwest Delta, with the latter having a larger capacity due to the daily elevated water level. The buffer in the Southwest Delta will naturally refill to the target level when there's sufficient river flow, as the total winter flow exceeds the buffer capacity.

Figure 5: an overview of strategy A2

(Ministerie van Infrastructuur en Waterstaat, 2024)

2.3.1.3. B1: Lockable sea front with the current flow distribution

Figure 6: an overview of strategy B1

(Ministerie van Infrastructuur en Waterstaat, 2024)

Strategy B1 involves a closeable storm surge barrier system in the Rhine-Meuse estuary and the Southwestern Delta. Additionally, the Rhine-Meuse estuary region and the Southwestern Delta (excluding the Western Scheldt) will have extra storage for peak river discharge and pumps. This storage and the pumps are primarily used when the storm surge barrier is closed.

The closure level of the storm surge barriers will moderately rise with sea level increases, causing daily water levels in non-dike areas to rise as well. The closure level is adjusted to limit the frequency of closures. Currently, at 2 m and 3 m above mean sea level, there is one closure per month during the winter season, totaling six closures per year. At 5.4 m sea level rise, the closure frequency would still be nearly daily with a closure level 2.5 m higher. However, Strategy B1 includes variants with an even higher closure level to further reduce the closure frequency.

The storm surge barriers at the IJsselmeer and the Amsterdam-Rhine Canal/North Sea Canal (ARK/NZK) are closed according to Strategies A1 and A2. The river discharge distribution remains unchanged. For freshwater supply, an additional buffer is created at the IJsselmeer and Markermeer, with capacity equal to that in previous Strategies A1 and A2.

As the current flow distribution remains the same, the impacts on the hinterlands will be bigger. This is as the levees next to the Rhine as well as the Meuse have to increase in size.

2.3.1.4. B2: Lockable sea front with an adjusted flow distribution

In Strategy B2, similar to Strategy B1, a closeable open storm surge barrier system is implemented. However, this strategy includes a modified river discharge distribution. During high river discharge (>12,000 m³/s), the existing rivers— Rijn, Waal, Boven-Merwede, Nieuwe-Merwede, Hollands Diep, and Haringvliet—will discharge water into the sea. To accommodate this, these rivers will be widened and deepened, creating a high-water corridor inspired by the 'Plan Beaufort.' The Meuse River will also connect to this corridor from the Lith weir.

Figure 7: an overview of strategy B2

(Ministerie van Infrastructuur en Waterstaat, 2024)

In the Haringvliet, a storm surge barrier will maintain tidal movement in the mouth of the high-water corridor. This barrier will close only during extreme storm surges or to prevent excessive salt intrusion, with a very low risk of failing to close. Sedimentation might occur in the corridor's mouth, benefiting nature but potentially requiring higher dikes.

Other lakes in the Southwestern Delta will connect to the Haringvliet and can be used for water storage. This strategy also includes a Delta Polder to regulate water levels around Rotterdam and Dordrecht to near sea level (NAP). The Delta Polder will be closed at the seaside on the Nieuwe Waterweg and have locks in the Spui, Dordtse Kil, and Beneden Merwede. The Lek River will drain into this polder, and pumps will discharge water to the sea to maintain NAP levels, protecting both dike and non-dike areas within the polder.

The Waal is chosen for primary water discharge as it currently handles most of the water flow. An alternative could divert water via the IJssel due to its wide riverbed, but this might cause issues for cities along the IJssel. The feasibility of this alternative requires further investigation, so the Lek and IJssel are not considered in Strategy B2.

2.3.2. Seawards

In this strategy a completely closed off barrier will be placed in front of the coast of the province of Zeeland in the southwest of the Netherlands. This will create a seaward coastal basin around the Rhine-Meuse estuary. The design involves a coastal basin from Walcheren to the outer contour of the 2nd Maasvlakte, with the Nieuwe Maas directly discharging into the sea, keeping the Port of Rotterdam and the 2nd Maasvlakte accessible for large sea vessels. It is important to note that this strategy is only effective if the length of the maintained coastline decreases.

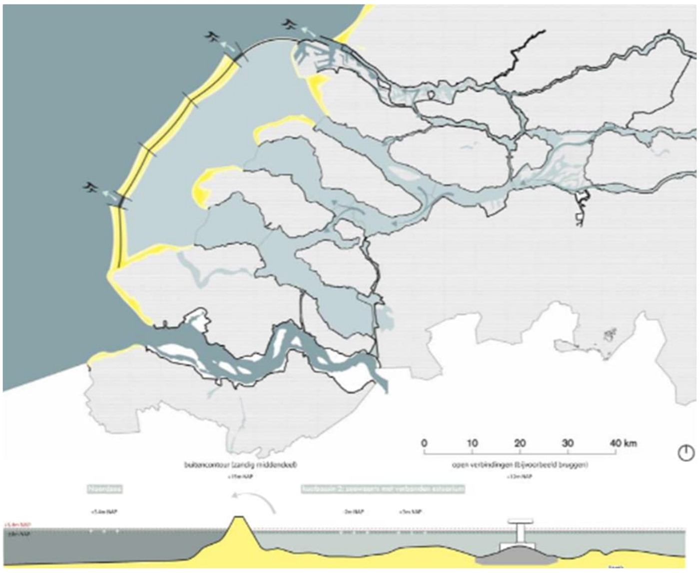

Figure 8: End situation of the "seaward" strategy.

(Ministerie van Infrastructuur en Waterstaat, 2024)

By pumping water in the coastal basin, water levels can be artificially lowered, maintaining low river water levels. The size of the basin depends on river discharges, extreme flow probabilities, and lake level fluctuations. The implementation is as follows:

Up to a 2-meter sea level rise, the policies for water safety remain the same.

To increase water storage for river water, estuaries like Haringvliet, Grevelingen, and Oosterschelde will be connected, creating about 1,000 km² of space to store river discharge.

From a 2-meter sea level rise, a seaward coastal basin of approximately 900 km² with a pumping capacity of about 3,800 m³/s will be constructed. This basin will not need further expansion with continued sea level rise.

The Waal and the Meuse will discharge into the coastal lake via Hollands Diep and Haringvliet.

When the sea level rise reaches 5.4 meters, pumping capacity must increase to 8,700 m³/s. The lake level can be lowered by 2 meters without sluicing to handle extremes.

Most components of the proposed "seaward" strategy are scalable or adaptable to further sea level rise. Large infrastructure elements like movable barriers or locks are less adaptable but are limited in the current design.

3 Development of the impact analysis

As previously mentioned, the primary objective of this project is to develop a methodology for gathering all direct and indirect impacts of implementing one of the long-term strategy building blocks and assessing the extent to which these impacts are qualifiable, quantifiable, and monetizable. A novel methodology will be developed to gather insights into the possible methods that might be applied.

Scientific innovation should be understood as a stage within a larger process that spans from invention to the diffusion of new ideas or methods (Sturm, 2019). This claim is supported by Wiles et al (2011), where it is stated that “Many claims to methodological innovation appear to be largely adaptations of existing methods rather than new methodologies or designs”. In this project the methodological innovation that is aspired to be created will be that of the adaptation of existing methods. Methodological development in qualitative social science is characterized by adaptations to tried and tested methods, the transfer of methods from other disciplines and changes in technology which enable researchers to collect or analyze data in different ways (Wiles et al., 2013). In this project, an attempt will be made to transfer methods from other disciplines. Namely, the inclusion of climatological analysis in an impact analysis.

As illustrated in Figure 2, the project can be divided into four steps.

Firstly, spatially identify the null alternatives and policy alternatives to establish a solid foundation for understanding the potential impacts of implementing a policy in a specific region. Spatial analysis hasbeen used in the scientific disciplines of earth sciences and economics for a multitude of benefits. It has been proven that spatial analysis is highly effective at projecting the impacts of climate change ata high resolution (Navarro-Racines et al., 2020). The scientific literature has shown that this is possiblefor a wide array of land-use change types. In the table below an overview is given from Briassoulis, H. (2020) for the multitude of different approaches to land use change. As is shown in the table, land usechange is a deeply analyzed and studied topic in different fields of science.

Table 1:A classification of Theories of Land Use Change, Briassoulis, H. (2020).

Category of Theorization Tradition	*Representative Approaches*
Urban and Regional Economics (and Regional Science)	• *Micro-Economic Theoretical Approaches* • *Macro-Economic Theoretical Approaches* • *Other Theoretical Approaches in Regional Science*
Sociological (and Political Economy)	• *Functionalist – Behaviorist Theoretical Approaches* • *Institutionalist-Structuralist Theoretical Approaches* • *Core-Periphery Theories* • *Unequal Exchange Theories* • *Uneven Development – Capital Logic Theories*
Nature-Society (Man-Environment or Human-Nature)	• *Humanities-Based Theories* • *Natural Science-Based Theories* • *Social-Science-Based Theories*

The second step is to compile a list of possible direct and indirect impacts through literature study. Environmental impact assessment (EIA) is a planning instrument for predicting the effects on the environment from altering or building a new establishment (Lenzen et al., 2003). Broadly speaking, evaluations can address three types of questions (Imas and Rist 2009):

- *Descriptive questions.* The evaluation seeks to determine what is taking place and describes processes, conditions, organizational relationships, and stakeholder views.

- *Normative questions.* The evaluation compares what is taking place to what should be taking place; it assesses activities and whether or not targets are accomplished. Normative questions can apply to inputs, activities, and outputs.

- *Cause-and-effect questions.* The evaluation examines outcomes and tries to assess what difference the intervention makes in outcomes.

Here Martinez (2011) states that "Impact evaluations are needed to inform policy makers on a range of decisions, from curtailing inefficient programs, to scaling up interventions that work, to adjusting program benefits, to selecting among various program alternatives". The method developed in this project will focus on cause-and-effect analysis, specifically aimed at assessing the impacts of various program alternatives. This approach will gather and evaluate how different alternatives affect outcomes, enabling a clearer understanding of their relative impacts.
For this step different experts will also be elicited. Knol et al (2010) states that expert elicitation cannot only provide valuable insights about quantitative uncertainties, but can also be applied to address qualitative issues, such as system boundaries, model structures, and assumptions. As Rijkswaterstaat has a vast array of experts, this knowledge will be used to increase the quality of thisproject. Here through the use of brainstorm session, further insights in the development of a methodology have been gathered.
The aforementioned impact list will be presented a table to clearly show which building blocks have impacted which categories of land-use.

The third step will establish a method for assessing the extent to which the impacts of different building blocks can be qualified, quantified, and monetized. This step will provide a clear overview of relevant impacts and their degree of monetizability, as well as identify negligible impacts that require no further attention.

Today, monetization of environmental impacts is mostly used in such contexts as (environmentally extended or social) cost-benefit-analysis (CBA) (Boardman et al., 2018). In figure the general steps are shown for relevant monetization methods. Here one can see that by missing one of the steps it is impossible to fully gain the true monetization. For this reason, it is for some types of studies impossible to gather the right data to fully monetize the results.

Some methods are relatively easy to monetize. For example, the methodology described in Steen (2016) achieves a high degree of monetization. Reasoning behind this is that in Steen (2016) the indicators are highly quantitative, making it easily monetizable.

However, certain methods like S-LCA (Social Life Cycle Analysis) are until time of writing impossible to monetize. This is because a S- LCA is largely based on qualitative or semi- quantitative indicators Bachmann et al. (2024).

Given the project's diverse range of sectors, there is a high likelihood of various degrees of monetization.

Lastly, the soundness of the methodology its suitability for broader research implementation will be done through the use of a case study of Holwerd.

The use of a case study allows for the opportunity to narrow in on the useability of the developed methodology. According to Yin (2009), case studies are ideal in research situations where the number of variables of interest far outstrips the number of datapoints. Given the complexity and multifaceted nature of this project, a case study allows for an in-depth exploration of numerous factors within the context of an impact area The case study approach can offer additional insights into what gaps exist in its delivery or why one implementation strategy might be chosen over another. This in turn can help develop or refine theory (Crowe et al., 2011)

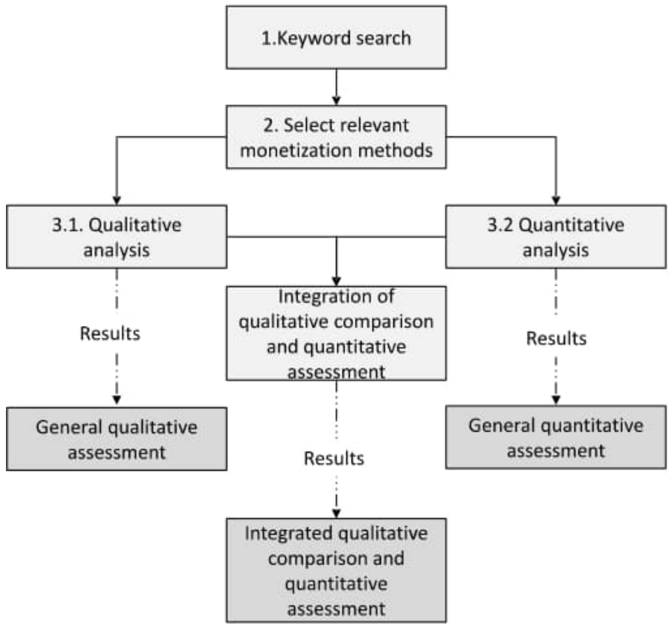

Figure 9: Steps to perform the review of the relevant monetization methods in LCA including linked results (displayed in a darker shade ofgrey) Arendt et al. (2020)

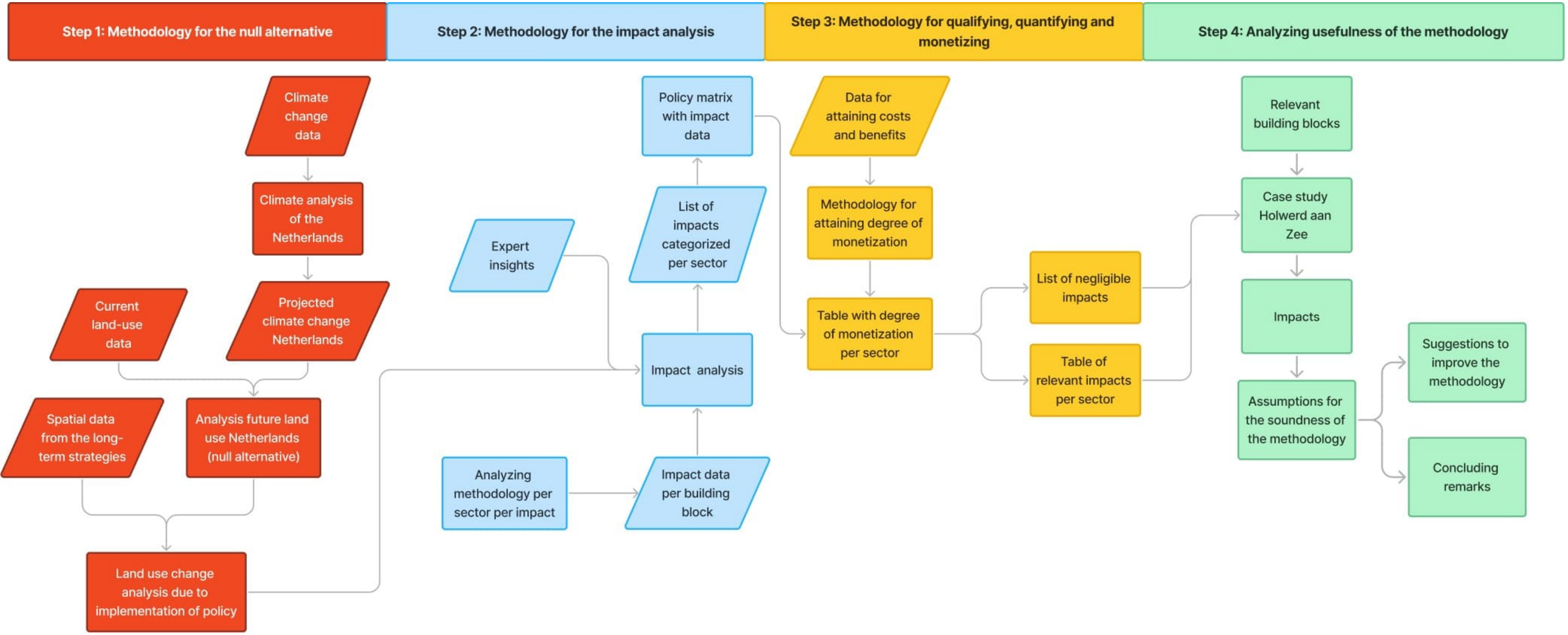

Figure 10: The flowchart of the methodolog

3.1. The null alternative

As stated before, the primary objective of this project is to develop a methodology for gathering all direct and indirect impacts of implementing one of the long-term strategy building blocks and assessing the extent to which these impacts are qualifiable, quantifiable, and monetizable. The general guideline for societal cost-benefit analysis will be used as the general outline for this project (CentraalPlanbureau et al., 2013).

A cost-benefits analysis compares the situation before implementing a measure or policy (the null alternative) with the situation after implementing the measure or policy (the policy alternative).

In this study the null alternative applies to all scenarios. So, it is a future scenario of the Netherlands with a sea-level rise of two meters and five meters. It is important to recognize that developments unrelated to climate change will continue independently. Since impacts can vary significantly by region, the most localized data available will be used to make assumptions about these non-climate- related developments. If local data is unavailable, the high scenario from the WLO (Welvaart en Leefomgeving, 2015) projections will be used instead.

The WLO or future forecast of prosperity and living environment is a rapport that provides possible images of the future regarding developments in:

- Population
- Macroeconomics
- Regional developments and urbanization
- Mobility
- Climate and energy
- Agriculture

Even though the rapport only creates scenarios until 2050, it is still possible to use at as a foundation to make assumptions regarding developments for the far future when the seas have risen by two meters and five meters, respectively.

Having a clear picture of the exact influences of climate change on the Netherlands is of the utmost importance. To acquire a sound methodology to analyze the impacts of climate change on land use change in the Netherlands, a literature review was done. The review will focus on similar projects that analyze changes in land use due to climate change. Many studies over recent years have analyzed the changes climate change brings to the climatological values of given regions of the world and the way the land is used by humans (e.g. Bandh et al., 2021; Bellard et al., 2012; Santos et al., 2020).

The literature review has shown that due to the nature of climate change almost no sector will be unaffected (Bandh et al.,2021). This is due to the fact that climate change impacts a wide range of variables which steers many parts of land use change. Regional variability makes it difficult to determine what the net positive and negative impacts will be (Mirón et al., 2023). Due to this, nearly spatial variability is often considered in climate related studies.

Using remote sensing provides more reliable insights for scientists and policymakers. As Boulos & Wilson (2023) states, "*Using GIS (geographic information systems) methods and software, experts can closely monitor these dangers. Robust geospatial data and detailed visualizations offer guidance for organizations and government agencies as they plan for the challenges ahead.*" As this methodology must be applicable for the entirety of the Netherlands it is essential that a solid remote sensing foundation will be lain down.

To achieve this, this project will use a wide array of data sources relevant to land use change in the Netherlands. This will be done in combination with GIS data to ensure relevant coverage of the impacted regions.

Data for the climatological changes in the Netherlands are taken from the most recent KNMI rapportson climate change projections in the Netherlands (KNMI, 2023). The KNMI is the Dutch national institute for weather, climate, and seismology. For this reason, it is the most accurate source of data when it comes to climate change predictions of the Netherlands.

This is (at the time of writing) the most comprehensive and up to date and therefore most suitable data source for this project. It will be supplemented with data from Klimaateffectatlas (2024) & Baptist, et al. (2019). This will be done for two scenario's The first is at a sea level rise of two meters and the other is for a rise of 5 meters. The rationale for this approach lies in the phased implementation of allstrategies. Initial changes are slated for approximately a 2-meter sea level rise, with full implementation planned by the time sea levels rise to 5 meters. For the GIS analysis LGN (2022) will be used.

LGN is the National land use database of the Netherlands. It provides the most accurate and recent GIS data we have of the Netherlands. This makes it the best source to use for spatial analysis.

Once the null alternative has been developed it is possible to make the policy alternative. Data will be taken from the 3 rapports released by the kennis programma zeespiegelstijging. It is important to note that only one of the three rapports "seawards" has given an accurate spatial aspect. The rapport "protect" has only given general locations, and the rapport " move with" none at all.

To still be able to make general assumptions about the impacts of the strategy "move with", a case study will be used. The reasoning for this case study is twofold. First, it allows for broader assumptions about the impacts of various building blocks. Second, it enables us to assess the soundness of the developed methodology. This approach helps to identify the advantages and disadvantages of the methodology and areas where further refinement is needed. Chapter 2.4 will go into detail about thereasons why a case study is an appropriate method for testing this methodology.

This case study will be done for the northern province of Frisia near the town of Holwerd. Here, we will make the same assumptions as those in the report "Move With": that after 2050, the existing water infrastructure and engineering structures will not be further improved. However, they will not be intentionally removed.

3.2. The impact analysis

After the relationship between the multiple building blocks and the spatial aspect have been mapped the direct and indirect effects of the implementation of the building blocks are analyzed. This is done by performing an impact analysis per building block. An environmental impact assessment will be the tool that is used to acquire understanding about the direct and indirect impacts. As stated by W.M.O. & G.W.P. (2013), “EIA (environmental impact assessment) assesses and predicts the impacts of a proposed project or action on human and ecosystem well-being.” This makes EIA an ideal framework for gathering impacts for this project. As it provides a checklist of environmental impacts, but it needs to be adapted to suit the specific needs of this project.

Figure 11: the thinking paths of brede welvaart

Therefore, the impacts will be divided according to the category of land use they influence. These categories are based on those from denkrichting brede welvaart. Brede welvaart is based on an analysis of existing models and studies, such as from the Central Bureau of Statistics, the Netherlands Environmental Assessment Agency for the Living Environment, and the Sustainable Development Goals of the United Nations (Ministerie van Algemene Zaken, 2022).

These brede welvaart tracks are supplemented by the EU’s CISES (Common International Classification of Ecosystem Services) (Haines-Young, R. & M.B. Potschin, 2017) list and the TEEB (The Economics of Ecosystems and Biodiversity) framework (TEEB, 2018). The CICES has been designed to help measure, account for, and assess ecosystem services. It has been used widely as the standard framework in ecosystem services research for designing indicators, mapping and for valuation (Haines-Young et al., 2018). The CICES was designed to help measure, account for, and assess ecosystem services. Haines-Young et al (2018) has shown that it has been used widely in ecosystem services research for designing indicators, mapping and for valuation. The TEEB framework addresses the limitations of traditional agricultural and food system assessments by considering the comprehensive interactions between eco-agri-food systems and the economy, society, environment, and health. Effective assessments using this Framework are broad and systemic, reflect all capitals' contributions, and examine the full value chain, including health impacts (Obst et al., 2018).

3.2.1. *The impact tables*

On the next page is shown the eventual tables that will be used to gather the degree to which it is possible to analyze the impacts. These categories of impacts are based on the categories of brede welvaart and those of the TEEB checklist provided in the framework. This has been done as brede welvaart is as of date of writing the thinking method of the ministry of infrastructure and water when it comes to the policy cycle. This makes the criteria that it provides ideal to analyse for this project. To prevent double counting from occurring for the aspect of ecosystem services, the CICES will be consulted and used as a baseline.

Here the divided into six categories. These categories are:

- Natural capital: The value of everything that comes from nature — soil, air, water and all living creatures (Knight, 2023).
- Living environment: An assembly of the natural and built environment which is offered to the inhabitants of the place who perform various kinds of social, cultural, religious, economic, and political activities which induce peculiarities in the character of the living environment (Tiwari et al., 2015).
- Social capital: The value derived from positive connections between people (Mask, 2019).
- Heritage: A version of the past received through objects and display, representations and engagements, spectacular locations and events, memories and commemorations, and the preparation of places for cultural purposes and consumption (Waterton & Watson, 2015).
- Reachability: the ease of accessing a given region (Truden et al., 2022).

Natural capital is based on all the impacts that the proposed measure might have on nature and its stocks. These are the impacts that directly change the state of the nature in a given region. They are based on a combination of the environment, nature & natural resources criteria's of brede welvaart and criteria in the checklist of the TEEB framework. One can argue that the largest impacted aspect is that of nature. For this reason, it is of the utmost importance that all the impacts on it are accurately covered.

Living environment accounts for all the impacts that might impact the direct surroundings and quality of living of an individual that is living in the affected region. They are based on the brede welvaart criteria of surroundings and climate. While nature outside of the urban area is influenced the most, it is also important to look at the influence on aspects of the urban area itself. For this reason, looking at the living environment is also crucial.

Social capital reflects the impacts that the measures will have on the lives of the inhabitants of the region. These aspects are based on a combination of the social cohesion, safety, social security & health criteria's of brede welvaart and criteria in the checklist of the TEEB framework. It is crucial that it is mapped what the implemented measures have as an impact on the livelihood of the inhabitants of the region.

Heritage gives an overview of the impacts that might occur on the cultural and natural heritage of a given region. The aspects are based on the cultural ecosystem services and the importance of maintaining (in)tangible heritage. Many of the potentially impacted areas contain heritage of some sort. It is important that the analysis also puts this into consideration.

Reachability analyses all the impacts that influence transport in the region. It is based on the reachability criteria of brede welvaart. As many of the building blocks have influence on the movement of people and goods it is critical that this aspect isn't overlooked.

The categories are divided into 2 different tables. This is to ensure that there is as little confusion about the legitimacy of the underlying source. This is due to the fact that CICES and “broad Wellbeing” are not equal when it comes to scientific legitimacy.

The CICES has been put under heavy scientific scrutiny. Even the website itself claims that it has been cited around 1000 times since it was published in 2018 (cices.eu). Here the CICES has not only been applied in impact studies (e.g. Ashley et al., 2023), but also been tested on it’s scientific applicability and usefulness. For example, Grima et al. (2023) has proven that the CICES is highly applicable to gain a degree of monetization using remote sensing for certain ecosystem services. Another study that delves into the applicability of the CICES is Czúcz et al. (2018). In Czúcz et al. (2018) a literature study has been conducted to assess the applicability of the CICES when it comes to monetizing impacts. In this paper Czúcz et al. (2018) states that “The CICES classification system as a whole seems to be reasonably comprehensive and instrumental”. Of all the papers analysed, around 20% of the indicators were monetized Czúcz et al. (2018).

This degree of scientific scrutiny is not yet the case for “broad wellbeing”. The concept of broad wellbeing was first proposed in 1934 by economist Simon Kuznets (Kuznets, 1934). However, this way of thinking has not been applied to policy making in the Netherlands for that long. Maas & Lucas (2023) states that in terms of use in policy practice, broad wellbeing is still in its infancy. This is not only regarding the Netherlands but also when looking at the European Union as a whole.

Table 2: the developed impact table based on the CICES

	Natural capital							Living environment						Heritage
Building block	Fresh water security	Water quality	Soil quality	Food security	Biodiversity	Size of nature	Consumption limited resources	Attractiveness of the spatial environment	Quality of housing and (green) amenities	Level of noise, vibration, and light	Local temperature	Greenhouse gas emissions	Water storage	Natural

Table 3: the developed impact table based on "broad wellbeing"

	Social capital																Heritage	Reachability		
Building block	Social cohesion	Safety				Livelihood security	Opportunities for empowerment	Trust in public institutions	Work opportunities	Costs of living	Innovation capacity and business climate	Size of the economy	Self-direction of people	Physical health	Mental health		Cultural	Commercial goods	Social	International reachability
		Regional	Social	Road	Water															

These tables serve to provide structure, outlining all impacts and their respective categories, offering policymakers a concise understanding of the anticipated changes (Lemmens et al., 2022). This approach serves two key purposes. Firstly, it ensures that the analysis encompasses all relevant effects and variables. Secondly, it facilitates the subsequent steps of qualifying, quantifying, and, where feasible, monetizing different direct and indirect effects. It is also useful the other way around; a clear and concise table can be used to illustrate what impacts might or might not be relevant for further research. In this project it is of utmost importance to have an as streamlined methodology as possible. Data from Hinrichs & Grant (2016) has shown that by having a clear overview of what is relevant and not, an increased amount of transparency is added to the method. In the case of this the relevant impacts are those that are significant and not yet put into consideration. Because of the latter, no impacts that have already been gathered by the "space for sea-level rise" will be put into consideration.

The impact analysis will primarily draw data from relevant sources of each of their respective categories. To ensure that the methodology is sound and that every variable is covered, expert knowledge is used. For this, experts from a wide variety of disciplines will be interviewed to guarantee that the methodology is sound, and their respective field isn't covered badly. Their knowledge will also be used to review the data. This will prevent that crucial variables will be left out. Beukers (2015) states that "Spatial strategic ideas need to be validated and legitimized in an interactive way through social encounters, discussion, debate, and exchanges of thoughts. This is especially relevant when different stakeholders with multiple frames of reference, rationales, and values are involved." For this reason, an as wide array of experts as possible will be consulted.

A significant risk of this research is so called double counting. Double counting occurs when a single building block is counted more than once towards a given impact (Schneider et al., 2014). This causes the implementation of a building block to have on paper a bigger up- or downside than it has in reality. To mitigate this risk, as outlined in (Ministerie van Infrastructuur en Waterstaat, 2022), it is necessary to ensure that the impacts across different categories are systematically interconnected and cross-referenced. By analyzing these interconnections, it is possible to identify and eliminate potential instances of double counting. Once the impact table is fully completed, a thorough comparative analysis of all categories is conducted to ensure that no effect is inadvertently counted more than once. This step is crucial for accurately reflecting the true impact of the building block.

3.3. Methodology for qualifying, quantifying and monetizing.

Once the impacts have been categorized by category, it is possible to analyze to what extend the impacts can be qualified, quantified, and monetized. This will be done through literature review, where for each category relevant literature will be analyzed to determine to what extend the impact is monetizable. Bull et al. (2022) proves that by developing a sound framework it is possible to gather enough data to quantify the effects of the implementation of a measure. Arendt et al. (2020) further supports this claim. They show that by finding the relevant data and monetization method it is possible to ascertain to what degree it is possible to qualify, quantify and monetize the different impacts. Schep et al. (2021) has done this to a further degree.

For this a step wised approach will be used similar to the one shown by Arendt et al. (2020) (PAGINA 17). First a qualitative analysis will be conducted to determine the potential positive and negative impacts. Then a qualitative analysis will be done to attain appropriate metrics and indicators to measure changes. Lastly, the qualitative changes will be monetized into euros.

It is important to note that not all impacts are as monetizable. For this reason, this bottom-up approach will be used. If a given impact, it will still be qualified and quantified using non-monetary metrics. This assures that all significant impacts will be considered, even if it is impossible to fully evaluate them.

For the current study, for each category, the degree to which it is possible to quantify, and monetize impacts, will be color-coded according to its category as is done in the TEEB framework. This gives a clear picture of the degree of monetization that is possible, enabling follow-up research to quickly obtain a clear picture of the research possibilities. This table will also show the possible methodology that can be used to attain this degree of monetization.

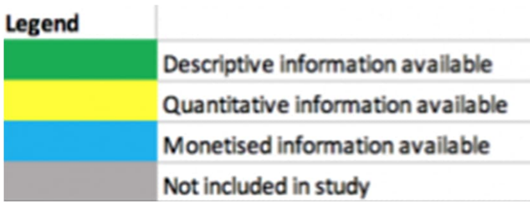

Figure 12: the colour coding as described in the TEEB framework.

3.4. Application of the case study

A case study will be implemented to test the methodology. "*A case study is one of the most extensively used strategies of qualitative social research"* (Priya, 2020). For this reason, it is a useful tool to determine whether the developed methodology is sound. Yin (2014) stated that a case study can be one of three things. It can be descriptive, explanatory, and most important the context of this study: exploratory. In these types of case studies, the purpose is to study a phenomenon with the intention of 'exploring' or identifying fresh research questions which can be used in subsequent research studies in an extensive way (Yin, 2014). In this rapport, the developed methodology will be tested to determine whether it withstands scrutiny.

Case studies have often times been used to test the effects of certain measures all across the globe. From cases in the Netherlands (e.g. Janssen et al., 2014), to studies in Europe (e.g. Markart et al., 2022) to studies on a global scale (e.g. Waghwala & Agnihotri, 2019). Case studies have also proven their worth when it comes to analyzing the effects of flood risk reduction measures like the ones in the long-term strategies (Marijnissen et al., 2021)

In this project a case study will be applied for the strategy " move with" in the region of northwestern Friesland (Frisia), around the village of Holwerd.

This location has been chosen for a multitude of reasons. First and foremost, this region has been analysed for this sort of measures before. This has caused there to be far more data availability for the effects of coastal flooding in this region. Another reason for this location would be that it is closely situated to not only urban cores, but also farmland and some critical infrastructure for the island of Ameland (LGN, 2022) This makes it an interesting region to look at as a wide array of land uses will be impacted.

All the steps outlined above will be followed. First, spatial data will be gathered about the region of northwestern Frisia and what potential building blocks are applicable in this region. Suitable locations for these building blocks will be identified based on land use. Then, the direct and indirect impacts will be analyzed, and the degree to which qualitative, quantitative, or monetary analysis is possible will be determined. This approach will provide insights into the advantages and disadvantages of the methodology, allowing recommendations to be made regarding its applicability for future research.

4 Case study Holwerd

For the case study building blocks from the strategy of “moving along” have been chosen. For this some assumptions have been made about the scenario of the case study. First and foremost, just as is stated in the rapport “move with” the assumption will be made that maintenance and improvements to the currently existing levees will remain up to standard until the year 2050. However, afterwards maintenance and improvements will seize to occur. This will bring with it an increased break in the levee, allowing the sea access land inward.

Here the assumption has been made that this break will not be repaired and that natural processes of the sea have free reign over the afflicted area. For this reason, the year 2050 has been used to simulate climatological changes as well as demographic changes.

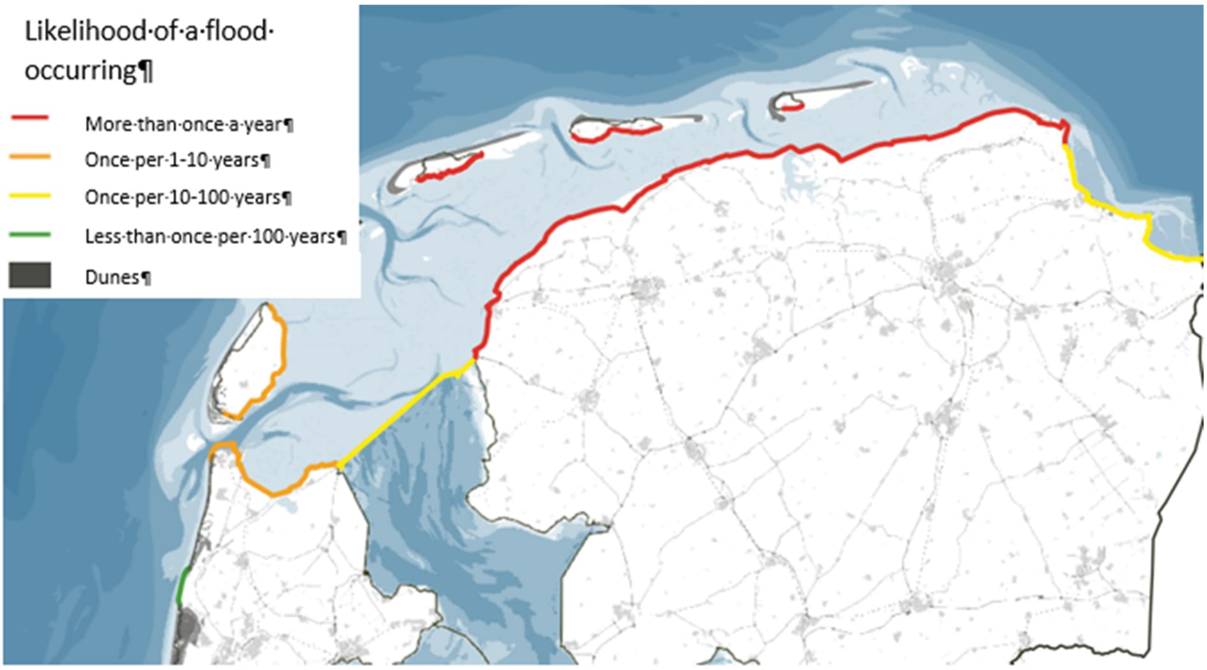

Figure 13: likelihood of floods occurring with two meters of sea-level rise.

In figure 9, it's evident that as the sea level rises by two meters, the probability of a breakthrough is expected to occur approximately once per year. This increased risk makes this section of levees interesting to look at. In this region the village of Holwerd has been chosen as the location for this break in the levee to occur. In figure 10 on the next page the chosen region for the case study is shown. This case study region is based on a natural variant without recreational boating (the lake functions as a nature reserve) scenario from Ruijgrok (2022).

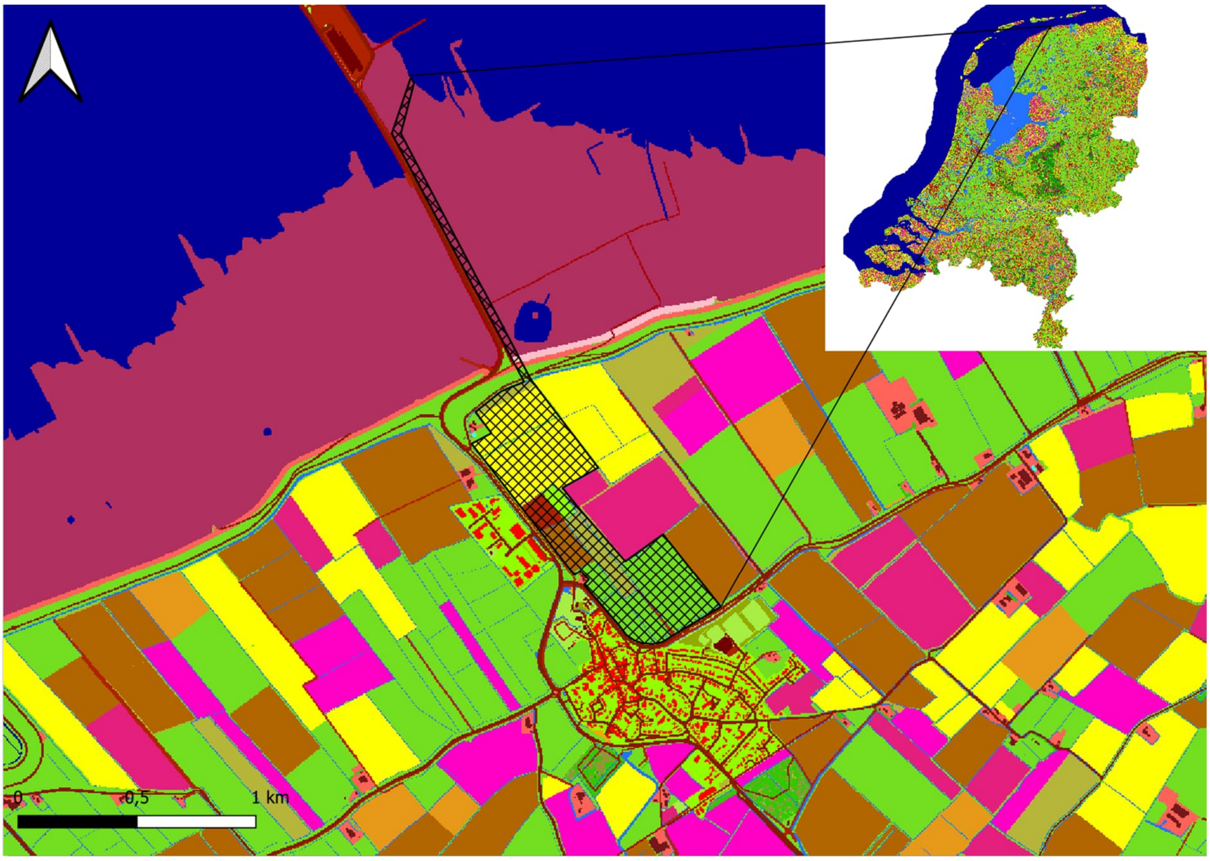

Figure 14: the case study area of Holwerd

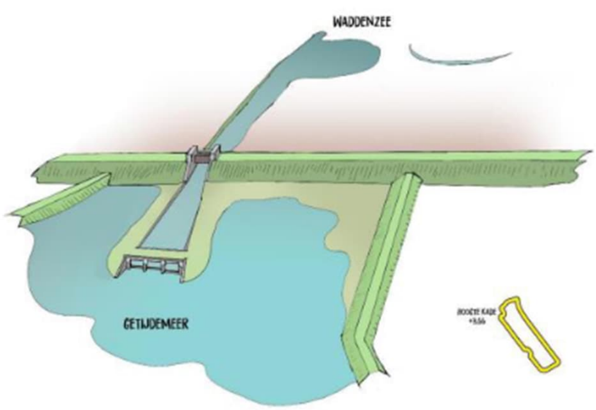

Figure 15: the control system with vertical lift gate

The case study area consists of the construction a connecting channel through the salt marsh outside of the main levee, and a tidal lake at Holwerd with bird islands, nature channels and recreational facilities. A control structure with a vertical lift gate provides a passage through the levee, creating tidal movement in the lake (Figure 15).

The same structure will be used for the case study as is described in the methodology.

First assumptions will be made about how the region will look in the year 2050. Using climatological and demographic data that is available about the region.

Then the building blocks will be identified. For this, previous studies looking at the impacts of "Holwerd aan zee" will be used. With this the impacts can be gathered and the degree to which they are able to be qualified, quantified, and monetized.

This will be shown in the table described in the methodology. Colour coding them based on the degree of monetization.

Afterwards, assumptions can be made about the usability of this methodology and importantly suggestions can be made about modifications to the proposed methodology.

4.1. the null alternative

As one might have noticed from figure 10, the predominant land use that will be impacted by the policy of “Holwerd aan zee” will be that of agricultural land use. However, the land use in the region might already have changed in the year 2050. In figure 16 & 17 below the change in land use between the current year and 2050 is shown.

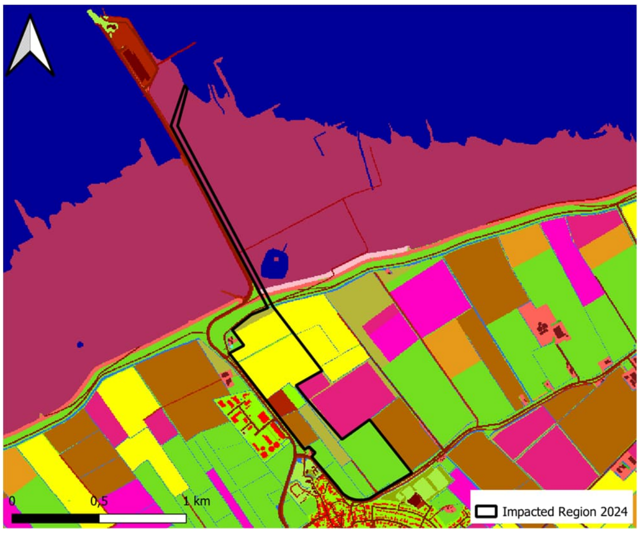

Figure 16: The land use in the case study area in the current year

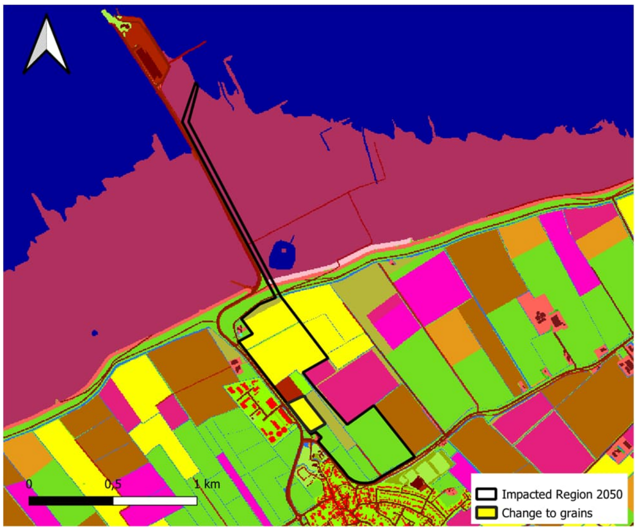

Figure 17: The land use in the case study area in the year 2050

When comparing land use in the current year and land use in the year 2050 it is noticeable that the changes due to climate change are still minimal. When analysing the region using Klimaateffectatlas (2024) some changes are of note. First and foremost, the salinisation map based on Delsman et al. (2023) shows that salinisation is contained into only a small part of the case study area. This plot of land contains potatoes that are relatively sensitive to salinity (STOWA, 2024). Snethlage et al. (2021) that to maintain sustainable agricultural productions two options are possible: preventative measures and adaptation of agricultural systems. The closest saline resistant crop to potatoes are grains (STOWA, 2024), so to adapt to the change in salinity the plot will convert from potato production to that of grains. However, even though one crop might be more saline resistant, the yield of the plot of land will still be lower than in that of optimal conditions (Van Den Burg et al., 2024).

The case study area also contains a parking lot for the ferry to the island of Ameland. A tourism analysis from de Waal et al. (2022) has concluded that there is a small growth in tourism to the island of around 3,8%. Because there is no reduction in tourism to Ameland the parking lot will still be there in the year 2050.

4.2. the impact alternative

Figure 18: the land use after the policy implementation

When comparing figure 16 with figure 18 vast differences in land use can be seen. The agricultural plots and the parking lot have been completely removed. In return, a vast space for nature has been created.

As stated before, this scenario is based on a natural variant without recreational boating (the lake functions as a nature reserve) scenario from Ruijgrok (2022). Because of this the building blocks are fully related to a land use change towards nature development.

4.3. Impact analysis & discussion

Table 4: the developed impact table based on the CICES

Building block	Natural capital							Living environment						Heritage
	Fresh water security	Water quality	Soil quality	Food security	Biodiversity	Size of nature	Consumption limited resources	Attractiveness of the spatial environment	Quality of housing and (green) amenities	Level of noise, vibration, and light	Local temperature	Greenhouse gas emissions	Water storage	Natural
Holwerd at the sea														

Table 5: the developed impact table based on "broad wellbeing"

Building block	Social capital															Heritage	Reachability		
	Social cohesion	Safety				Livelihood security	Opportunities for empowerment	Trust in public institutions	Work opportunities	Costs of living	Innovation capacity and business climate	Size of the economy	Self-direction of people	Physical health	Mental health	Cultural	Commercial goods	Social	International reachability
		Regional	Social	Road	Water														
Holwerd at the sea																			

The main purpose of this rapport is to develop a methodology. For this reason, the impact analysis was done through the form of a literature review of Warringa et al (2018) and Ruijgrok (2022).

This literature study has shown that the given impacts by this policy measure can be monetized. However, if the methodology proposed in this study would have been applied there would have been differences in the results of some of the variables. Ruijgrok (2022) was able to evaluate the loss in agricultural value in euros (Food security). But the loss in value due to climate change wasn't put into consideration. Because of this the costs of change for this impact are higher than it would be in practice.

Another thing of note are the many variables that are not included in the study. This is because the case study area is in rural area and predominantly impacts one land use type. The not included variables are simply not impacted by the measures taken in the project Holwerd at the sea. Another reasoning for the exclusion of certain variables is because the weren't included in Warringa et al (2018) or Ruijgrok (2022) even though they might as well have been impacted by Holwerd at the sea.

When analysing this methodology further additions that need to be included to solidify it come to mind.

First and foremost, the spatial aspect must be refined more. In this paper only the directly impacted area has been put into consideration. However, the decisions made in a policy might influence a wider region. The likelihood that the methodology covers all potential impacts is severely higher if not only the direct environment is put into consideration but also the indirect variables that are influenced due to the changes in the direct impact area.

Secondly, the methodology for listing and analysing of (anti-) synergies between different building blocks needs to be expanded upon. In its current form the table has no method of showing that the given score is given due to an (anti-) synergies between two or more building blocks. Because the interconnectivity is an important part of this project it is important that the table will be adjusted in further research to include this. This will allow policymakers to clearly see the advantages and disadvantages of combining certain building blocks.

Third of all, as was done in Ruijgrok (2022), a discount rate needs to be included. Applying a discount rate will help policy makers gather the true value of implementing a measure in the far Future, once again strengthening their ability to make a decision.

Fourth, an uncertainty analysis needs to be included into the framework. The inclusion of an uncertainty analysis will not only provide insight, but also improve the reliability and robustness of the results. This is crucial for identifying risks and understanding the range of possible outcomes. Helping policy makers make more informed decisions when using this methodology for gathering impact data.

Lastly, the inclusion of a stakeholder analysis will benefit this methodology. This will not only vastly improve societal support for the implementation of these long-term strategies, but also make the results more representative for the many different groups living in the impacted region.

5 Conclusion

This case study has shown that it is possible to make assumptions about the direct and indirect impacts for policies that will be enacted in the distant and possibly far future. Here it is one can argue that with this, policymakers should be able to enact precautionary preparations more confidently like land reservations for enacting long-term policy decisions.

However, precaution needs to be taken when predicting future impacts. High spatial variability occurs. Not only when deciding the location of implementing a given building block, but also in the way climate and demographic changes are enacted upon a given region that is to be studied.

While it is possible to reduce it, it is impossible when looking at policy impacts of the future to completely remove uncertainties. However, by working on a small spatial scale and with high quality localised data it is possible to reduce this as much as possible. The methodology has shown that with the currently available climatological data it is possible to make accurate assumptions about the land use change of the future in the region where the policy impacts will take place.

By using common impact analysis methods on these projected regions, policy makers will be able to estimate the potential direct and indirect effects that will occur. By using these impact analysis methods, it is possible to make assumptions about the degree to which an impact can be qualified, quantified, and monetised. Here further development to the methodology is recommended to accurately indicate the interconnected synergies between building blocks.

So, to recommend going ahead in the project “space for sea-level rise” it is advisable to look for solutions not only on multiple spatial scales to prevent any impacts from being left out, but also to look at synergies in between the different building blocks. It is recommended that further development to the methodology will take place using the suggestions outlined in the discussion. This is to make the most optimal policy to protect the Netherlands from long-term sea-level rise.

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