Ecosystem-based Adaptation

An incremental cost-benefit analysis of a breakwater of stones and an oyster reef in the Eastern Scheldt

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Ecosystem-based adaptation is increasingly being mentioned as a measure against the adverse effects of climate change. Oyster reefs have the potential to serve as an ecosystem-based adaptation measure. The objective of this thesis is to explore whether an oyster reef or a breakwater of stones is a more cost-effective measure against coastal erosion in the Eastern Scheldt. This is done by performing an incremental cost-benefit analysis of an oyster reef as compared to a breakwater of stones, including tangible and non-tangible costs and benefits. The results of the analysis indicate that oyster reefs are a more cost-effective measure. However, the study was hampered by the lack of quantitative data to fully justify the use of oyster reefs instead of a breakwater of stones.

ENR-80536: MSc Thesis Environmental Economics & Natural Resources

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June 3, 2020

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Preface

Before you lies the thesis ‘’Ecosystem-based Adaptation: An incremental cost-benefit analysis of a breakwater of stones and an oyster reef in the Eastern Scheldt’’. This thesis is written in order to explore the whether an oyster reef or a breakwater of stones is a more cost-effective measure against coastal erosion.

At first, I would like to thank my supervisor from the Environmental Economics and Natural Resources Group at Wageningen University, Francisco Alpízar Rodriguez, for guiding and supporting me during this process. Your helpful feedback helped me a lot in the process of writing this thesis. It is a pity that the major share of our meetings were forced to be digitally due to the COVID-19 pandemic.
Secondly, I would like to thank Brenda Walles from Wageningen Marine Research for explaining the project of oyster reefs in the Eastern Scheldt, providing me with relevant literature and data, and helping me out when needed.
At last, I would like to thank Klaas Kaslander from Waterschap Scheldestromen for providing me with information and (cost) data concerning breakwater of stones.

1. Introduction

Ecosystem-based adaptation (EbA) is increasingly being mentioned as a measure against the adverse effects of climate change. As the CBD (2009, p. 6) definition states: *''Ecosystem-based adaptation uses biodiversity and ecosystem services in an overall adaptation strategy. It includes the sustainable management, conservation and restoration of ecosystems to provide services that help people adapt to the adverse effects of climate change''.* An example of ecosystem-based adaptation are using mangrove forests as coastal protection. By sheltering coastlines during storm events, economic damages resulting from these storms are reduced (Hochard et al., 2019). Besides being a measure against the impacts of climate change, EbA measures often also provide an array of ecosystem services that can benefit different groups of society. This leads to EbA having great potential to be implemented on a larger scale. However, for this to be realized, more investment into EbAs has to take place. Furthermore, EbA should be more integrated into climate policies (IUCN, 2019).

In this master thesis, the case of building an oyster reef in the Eastern Scheldt as an EbA measure to mitigate coastal erosion will be examined. It will be compared to the traditional situation, a breakwater of stones, in terms of its cost-effectiveness.

The oyster reef (*Crassostrea gigas)* is built on the tidal flat to serve as a measure against coastal erosion. Besides providing protection against coastal erosion, oyster reefs also provide a range of other ecosystem services, e.g. carbon sequestration, water filtration. In order for oyster reefs to generate more (public) support, there needs to be a clear view of the (monetary) costs and benefits that come with such a project. This also holds for the integration of such measures into climate policies. Given that oyster reefs might generate benefits that accrue to multiple stakeholders, it is important to identify those stakeholders and their monetary stake in the establishment of these EbA measures.

The objective of this thesis is to explore whether an oyster reef or a breakwater of stones is a more cost-effective measure against coastal erosion. This is done by performing an incremental cost-benefit analysis of an oyster reef as compared to a breakwater of stones, including tangible and non-tangible costs and benefits. The analysis in this thesis therefore does not try to nor can calculate the value of either a breakwater of stones or oyster reef. It only provides an indication of the incremental value of an oyster reef as compared to a breakwater of stones.

This master thesis addresses the following four research questions:

1. What is meant by ecosystem-based adaptation, and how can oyster reefs be used as ecosystem-based adaptation?
2. Which ecosystem services are provided by oyster reefs and who are the likely corresponding beneficiaries?
3. What is the value of the relevant ecosystem services provided by oyster reefs?
4. How do oyster reefs compare to a breakwater of stones in terms of cost-effectiveness?

There are several methods that were being used in order to answer these research questions. The first two research questions were answered by doing a literature review, consisting of both peer-reviewed articles and research reports. Existing information and data on several topics, such as adaptation, oyster reefs and their provision of ecosystem services was gathered. An expert interview with Brenda Walles from Wageningen Marine Research, who is currently working on the project, also contributed to answering these research questions. The third research question was answered by using the information obtained by the literature review and applying it to the case of constructing an oyster reef as EbA measure in the Eastern Scheldt. The fourth and last research question was answered by using all the information previously obtained and incorporating this information into an incremental cost-benefit analysis.

Chapter 2 describes the concepts of adaptation, adaptive capacity, resilience and ecosystem-based adaptation. These concepts are then applied to the case of oyster reefs in the Eastern Scheldt. Chapter 3 describes the different types of ecosystem services according to The Millenium Ecosystem Assessment (MEA, 2005), followed by a description of different types of values that can be attributed to ecosystem services. Chapter 4 then applies these different types of ecosystem services to the case of oyster reefs in the Eastern Scheldt, where the ecosystem services provided by oyster reefs are explained. Chapter 5 describes the beneficiaries of each of the ecosystem services that are included in the cost-benefit analysis, as well as the different kind of values that are attached to these services. Chapter 6 consists of a description of the different scenarios, or ‘’states of nature’’ that are included in the cost-benefit analysis. It also describes the time horizon and discount rate that will be used in the cost-benefit analysis. This is followed by the results of the analysis in chapter 7, starting with the estimates of both the costs and benefits, followed by the comparisons between different scenarios. The discussion is presented in chapter 8, describing the limitations of this thesis, and proposing opportunities for further research. At last, chapter 9 concludes.

2. Adaptation & Ecosystem-based adaptation

In this chapter, the concepts of adaptation, adaptive capacity, resilience and ecosystem-based adaptation are explained. These concepts are then also applied to oyster reefs.

2.1 Adaptation

Adaptation can have different meanings. In biology, adaptation is referred to as ‘’*an organism’s response to its surrounding environment’’* (Engle, 2011, p. 648). This includes learning and adjusting to a surrounding environment. The IPCC (2014, p.118) defines adaptation as *‘’the process of adjustment to actual or expected climate and its effects’’.* This definition focusses more on the human perspective of adaptation. Humans can take measures to mitigate certain effects that are expected to take place somewhere in the future, whereas other living organisms can often not do this. Another difference between biological adaptation and adaptation from a human perspective is that from a human perspective, adaptation does not only try to moderate or avoid harm, but also tries to exploit beneficial opportunities (IPCC, 2014).

The form of adaptation in biology that is often mentioned with regard to climate change is reactive or autonomous adaptation. This form of adaptation refers to the innate ability to adapt to one’s environment (Tompkins & Adger, 2005). However, if you look at adaptation from the human perspective, such as the IPCC definition, then adaptation mostly is proactive and non-autonomous. The ecosystem-based adaptation practices that are the focus of this thesis are regarded as proactive and non-autonomous adaptation.

2.2 Adaptive capacity

The IPCC (2014, p. 118) defines adaptive capacity as *‘’the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences’’*. So whereas adaptation refers to the actual adjustment to certain effects, adaptive capacity refers to the ability to adjust, take advantage, or respond to certain effects. Gallopín (2006) argues that the IPCC definition might be too restrictive, since certain adaptations might include a modification of a system’s sensitivity to disruptions. Engle (2011, p. 652) states that *‘’adaptive capacity is a universally positive system property’’*. This means that adaptive capacity is never described in negative terms and a system can never have too much of it. As stated by Adger et al. (2007), adaptive capacity is not always equal for the same ecosystem, but rather varies between different contexts and systems. It therefore is important to develop context-specific measures instead of coming up with one-size-fits-all measures.

2.3 Resilience

As defined by the IPCC (2014, p. 127), resilience is *‘’the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation’’.* This means that resilience refers to going back to the initial state of a system, where the system maintains its essential function. As described in the definition, resilience is related to adaptation. However, in a situation where a system adapts to a certain stressor, it is possible that the system can change to a new state. This shows the difference between adaptation and resilience.

Generally, it is difficult to draw insights that are generalizable to various policy contexts with regard to resilience. The first reason is that the policies made by decision makers are often based on certain scales and borders, but these often present a mismatch with the ecological boundaries of a system (Cumming et al., 2006). The second reason is that resilience is often differently interpreted between scholars and practitioners. The main cause of this different interpretation is because of inconsistencies in the characterization of resilience over the past years. Scholars often interpret resilience as ‘’social-ecological resilience’’, whereas practitioners tend to use resilience as ‘’engineering resilience’’, which can be seen as a return to a single, stable equilibrium (Engle, 2011).

2.4 Ecosystem-based adaptation

Ecosystem-based adaptation (EbA) is increasingly being mentioned as a measure against the impacts of climate change. As the CBD (2009, p. 6) definition states: *‘’Ecosystem-based adaptation uses biodiversity and ecosystem services in an overall adaptation strategy. It includes the sustainable management, conservation and restoration of ecosystems to provide services that help people adapt to the adverse effects of climate change’’.* This is different from the ‘’business as usual’’, where one often tries to build and/or work against nature to reduce vulnerability to climate change. This is also mentioned by FEBA (2017), since they describe that EbA differs from ‘’business as usual’’, since EbA links biodiversity and ecosystem conservation approaches with sustainable socio-economic development. This shows that EbA, besides building resilience to climate change, also aims to foster sustainable socio-economic development. Showing that the measure also supports socio-economic development, instead of just being a measure against climate change, could increase public support for such measures.

EbA can be seen as people-centric, since, as stated in the previously mentioned definition, it focusses on potential benefits that humans can derive from biodiversity and ecosystems in order to build resilience to climate change. It also states that humans are largely dependent on these biodiversity and ecosystems. However, EbA should be implemented as an integrated element of broader adaptation strategy, since ecosystem health by itself does not automatically guarantee human resilience to climate change (FEBA, 2017).

2.4.1 EbA criteria

Concerning political commitment, it is beneficial for policymakers and practitioners to have a more clear view on when a measure qualifies as EbA. FEBA (2017) composed a framework that involves five criteria that have to be met in order for an activity to be qualified as EbA. I will also use this framework, since it is a widely accepted framework which has also been implemented by, among others, the IUCN (International Union for Conservation of Nature) and IIED (International Institute for Environment and Development). These are international institutions that are globally recognized and provide a lot of work on such a topic as EbA.

According to FEBA (2017), there are five criteria that have to be met in order for an activity to be qualified as EbA. The activity should (1) reduce social and environmental vulnerabilities; (2) generate societal benefits in the context of climate change adaptation; (3) restore, maintain or improve ecosystem health; (4) be supported by policies at multiple levels; and (5) support equitable governance and enhances capacities.

The first criteria forms the basis of EbAs, since the main aim of EbAs is to help people adapt to the adverse effects of climate change. Concerning this criteria, both current and future climate change and climate variability should be addressed. So for an activity to qualify as an EbA measure, it should be clear that the activity reduces social and environmental vulnerabilities (FEBA, 2017).

The second criteria closely relates to the first criteria, since they both relate to the actual adaptation to the adverse effects of climate change. An EbA measure delivers both direct and indirect benefits concerning people's resilience to climate change, e.g. shelter, risk reduction. Besides these benefits, additional benefits are often provided by EbA measures, such as carbon sequestration, habitat provision, and climate regulation. These benefits provided by EbA measures should be short-, medium- and, long-term. Concerning the distribution of these benefits, they should be distributed fairly among the target group of the EbA (FEBA, 2017).

The third criteria states that next to building resilience against the adverse effects of climate change, the health of the ecosystem that is involved in the EbA measure should be restored, maintained or even improved. This will also favour human well-being, since, as previously mentioned, humans largely depend on biodiversity and ecosystems. A healthier ecosystem will therefore also be beneficial for the humans that interact with the specific ecosystem. Several measures can be included in EbA, such as ecosystem management and restoration of natural infrastructure. These measures can help to contribute to restoring, maintaining or improving the ecosystem health (FEBA, 2017).

Since EbA is part of an overall adaptation strategy, it operates at one or more levels, e.g. local, regional, national. This requires EbA to be supported by policies at multiple levels, which is the fourth criteria. Integrating EbA into existing policy frameworks can support EbAs to be sustainable and scalable, instead of having a short-term view (FEBA, 2017).

As the fifth criteria, FEBA (2017) state that fair and equitable sharing of user access should be supported by EbA. Furthermore, by having a community-centered and participatory approach, EbA enhances governance of natural resources. This helps in enhancing capacities for local people who are using and benefitting from the biodiversity and ecosystem services. Ownership by these people can ensure that benefits emerge and are sustainable, since they are dependent on the biodiversity and ecosystem for their well-being. Strong local governance can help in achieving these goals (FEBA, 2017).

2.4.2 EbA example

A well-known example of EbA are mangrove forests. Mangroves shelter coastlines during storms by dissipating wave energy. Hochard et al. (2019) found that it may be more cost-effective to restore mangrove forests concerning coastal protection, whereas mangrove deforestation may be more damaging than one previously thought. Baig et al. (2015) researched the costs and benefits of building a mangrove forest as compared to an engineering option, a seawall. It turned out that the EbA option provided more economic net benefits in the long-run as compared to the engineering option. This is especially true when co-benefits are considered, such as contribution to fisheries.

2.5 Oyster reefs in the Eastern Scheldt

As has been mentioned in the introduction, this thesis focusses on oyster reefs to battle coastal erosion in the Eastern Scheldt as an EbA measure. Located in the Southwest of the Netherlands, The Eastern Scheldt estuary is a 351 km^2 tidal basin consisting of 118 km^2 of tidal flats. Currently, around 8 percent of the tidal flats (9 km^2) is covered with natural oyster reefs (Walles et al., 2016). The project is still a pilot, since results have to indicate whether the project can be implemented on a larger scale. A substrate of Pacific oyster shells is placed on the tidal flat, in order to grow such a reef (EcoShape, n.d.a). Over time, oyster larvae attach themselves to the shells, which ultimately leads to a solid reef structure. This is also an advantage of using oysters instead of other shellfish, because oyster stay attached to the reef when they die, which contributes to the formation of a solid reef structure (EcoShape, n.d.b).

Oyster reefs are ecosystem engineers, which are *''organisms that directly or indirectly modulate the availability of resources (other than themselves) to other species, by causing physical state changes in biotic or abiotic materials. In doing so they modify, maintain and/or create habitats''* (Jones et al. 1994, p. 373). Oyster reefs' most important functions with regard to functioning as coastal protection, as stated by EcoShape (n.d.a), are protection against coastal erosion; reduction of hydraulic forces by dissipating wave energy and increasing sediment deposition and erosion reduction; and enhancement of biodiversity, biomass, productivity and functioning of the ecosystem. By constructing an oyster reef, one tries to minimize a further increase of coastal erosion. Furthermore, by dissipating wave energy, an oyster reef reduces the possibilities of damage due to storms. This approach shows that this EbA measure is proactive and non-autonomous.

An oyster reef alone cannot serve as the sole coastal protection measure, the reefs should therefore be used in combination with primary flood defence systems, e.g. dams or dikes. By reducing hydraulic forces, such as waves and currents, an oyster reef can serve as an extra barrier in front of the primary coastal defence (EcoShape, n.d.a).

2.5.1 EbA criteria Eastern Scheldt

The five criteria a practice has to meet in order to qualify as EbA, stated by FEBA (2017), will be discussed concerning the oyster reef.

The first criteria, that the activity should reduce social and environmental vulnerabilities is being met by the project of constructing oyster reefs. As just has been described, oyster reefs reduce coastal erosion, and can serve as coastal protection. Furthermore, oyster reefs enhance the overall functioning of the corresponding ecosystem. These effects reduce both social and environmental vulnerabilities.

The second criteria, that the activity should generate societal benefits in the context of climate change adaptation, is also met by the project. As has been mentioned, this criteria closely relates to the first criteria, since they both relate to the actual adaptation to the adverse effects of climate change. Oysters reefs generate societal benefits by reducing coastal erosion and providing coastal protection. Furthermore, oyster reefs filter water, which leads to an increase in water quality. Also by enhancing the overall functioning of the ecosystem, oyster reefs contribute to the food provisioning service of the ecosystem, by providing habitat for fish. Besides, oysters can be harvested for human consumption, but this might negatively affect the oyster reef's ability to provide other ecosystem services (Walles et al., 2015a)(EcoShape, n.d.a.).

The third criteria is that the activity should restore, maintain or improve ecosystem health. As just has been mentioned, oyster reefs are ecosystem engineers and furthermore, they enhance the overall productivity and functioning of the ecosystem. However, some consider the Pacific oyster to be an invasive species in the Eastern Scheldt. But the Pacific oyster can also be seen as a replacement of the Dutch oyster, that has been decimated by a disease. Its ecosystem services are still plentiful, e.g. habitat provision. The presence of the Pacific oyster is therefore related to certain protected nature values in the Eastern Scheldt (EcoShape, n.d.a.) This altogether shows that the project meets this criteria.

The fourth criteria, that the activity should be supported by policies at multiple levels is not yet met by the project, but there is potential that it can be in the future. Brenda Walles from Wageningen Marine Research, who is currently working on the project, stated that there is still some opposition concerning the project, also among higher authorities, such as Rijkswaterstaat. She stated that the project team should focus on trying to create a support base for the project, in order to make sure that the project will be implemented on a larger scale, and be part of a larger overall policy framework (Walles, pers. comm). La Peyre et al. (2012) also state that, among other things, political support is necessary for successful oyster reef restoration.

The fifth criteria, that the activity should support equitable governance and enhances capacities, can somewhat be regarded to in the same way as the fourth criteria. The criteria states that by having a community-centered and participatory approach, EbA enhances governance of natural resources. This is also not yet met by the project, but is possible in the future. As will be discussed later on in this thesis, oyster reefs provide several benefits that benefit local communities. By engaging these local communities in the project, one can meet this criteria. In the United States, there are also several projects being executed concerning the construction and/or restoration of oyster reefs, where stakeholder cooperation is being used. For example, the research by La Peyre et al. (2012) shows that stakeholder cooperation is necessary for successful oyster reef restoration.

So overall, the first three criteria are already met by the project. The fourth and fifth criteria are not yet met, but there are possibilities that these will be met in the future. Since the project is a pilot and is not yet implemented on a larger scale, it is assumed that these criteria will be met if the project will be implemented on a larger scale. It is therefore assumed that the project qualifies as an EbA measure.

3. Ecosystem services

This chapter explains the concept of ecosystem services and the corresponding categories, according to The Millennium Ecosystem Assessment (MEA, 2005).

3.1 Ecosystem services

According to The Millennium Ecosystem Assessment (MEA, 2005), *''an ecosystem is a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit''* (MEA 2005, p. V). Subsequently, they define ecosystem services as *''the benefits people obtain from ecosystem''* (MEA 2005, p. V). These ecosystem services can be divided into several categories according to the framework provided by MEA (2005), which include supporting, provisioning, regulating and cultural ecosystem services. Each different category accounts for different types of ecosystem services, which will be discussed later in this chapter. The Millennium Ecosystem Assessment (MEA, 2005) provides a conceptual framework that shows the different categories of ecosystem services and how these are linked to human well-being. This framework is shown below in figure 1.

Figure 1. *Linkages between ecosystem services and human well-being* (MEA, 2005).

3.2 Types of ecosystem services

3.2.1 Supporting ecosystem services

Supporting ecosystem services are a prerequisite for other ecosystem services to be produced by the corresponding ecosystem. In other words, supporting ecosystem services can be seen as the foundation of all other types of ecosystem services (MEA, 2005). Logically, supporting ecosystem services include several fundamental services. Figure 1 provides some examples, e.g. nutrient cycling, soil formation, and primary production.

3.2.2 Provisioning ecosystem services

Provisioning ecosystem services are the actual products that are obtained from ecosystems (MEA, 2005). For example, timber, food, and genetic resources. The value of these provisioning ecosystem services are generally easier to determine as compared to the other ecosystem services, because these obtained products are often marketed, meaning that they have market prices.

3.2.3 Regulating ecosystem services

Regulating ecosystem services are services that are related to the regulation of ecosystem processes, and the benefits that people obtain from these services (MEA, 2005). Examples of these services are climate regulation, flood regulation, shoreline stabilization, carbon storage and water purification. These examples show that certain ecosystems can greatly contribute to mitigating the adverse effects of climate change.

3.2.4 Cultural ecosystem services

Cultural ecosystem services are benefits that people obtain from ecosystems through recreation, aesthetic experiences, spiritual enrichment, reflection, and cognitive development. These are nonmaterial benefits (MEA, 2005). Tourism is a well-known example of a cultural ecosystem service.

3.3 Types of values attributed to ecosystem services

When valuing ecosystem services, there are several value types that can be attributed to these services. The most common are (1) direct use values; (2) indirect use values; (3) option values; and (4) non-use values. Figure 2 provides an overview of these different values and how they together make up the total economic value (TEV) of an ecosystem (Bartkowski, 2012).

3.3.1 Direct use values

Direct use values are the most straightforward type of valuation. Direct use values relate to the direct usage of ecosystems, both consumptive and non-consumptive (Pearce & Turner, 1990). All provisioning services and some cultural services have direct use values (Hein et al., 2006).

3.3.2 Indirect use values

Indirect use values relate to the indirect usage of ecosystems, mainly by positive externalities provided by the ecosystems. Regulating ecosystem services have indirect use values (Hein et al., 2006).

3.3.3 Option values

Option values are different from direct and indirect use values, because they relate to the future use of the ecosystem service. Perman et al. (2003, p. 402) defines option value as: *‘’Option value relates to willingness to pay to guarantee the availability of the service for future use by the individual’’*. By guaranteeing the future availability of a service, one can avoid the risk of the service not being available in the future. Option values can be attributed to every type of ecosystem service that is provided by a certain ecosystem (Hein et al., 2006).

3.3.4. Non-use values

If an ecosystem service has a non-use value, it means that the particular ecosystem service has a value that is not associated with the actual use of that service. It rather has a value in itself (Kareiva et al., 2011). Non-use values can be determined from two perspectives. Firstly, from an anthropocentric viewpoint, which relates the human perspective. Secondly, from an ecocentric viewpoint, which for example can state that a certain species has the right to exist (Hargrove, 1989). As shown in Figure 2, non-use values can be divided into three different types, these are bequest, altruist, and existence value (Kolstad, 2000).

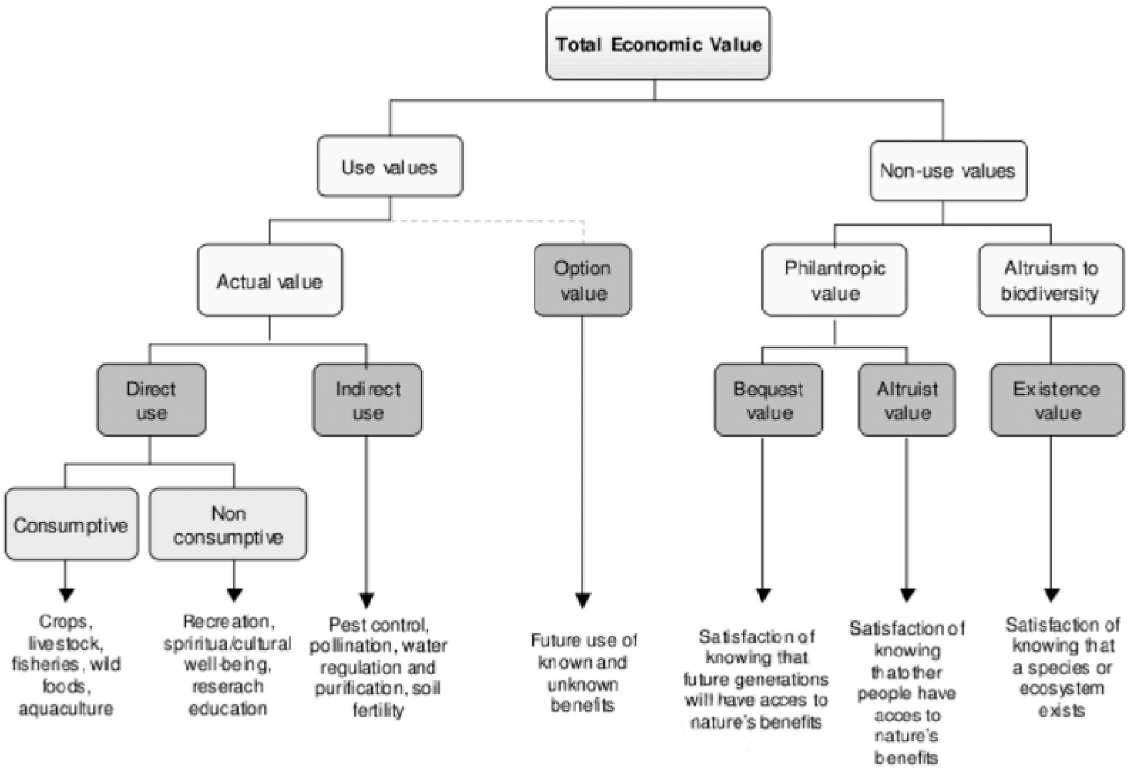

Figure 2. *Total economic value framework* (Bartkowski, 2012).

4. Ecosystem services provided by oyster reefs

Oyster reefs provide a wide range of ecosystem services. As just has been described, ecosystem services can be divided into four categories, according to the MEA framework.
There are roughly seven main ecosystem services that are provided by oyster reefs (Grabowski et al., 2012). This chapter divides these ecosystem services into those four categories.

4.1 Supporting ecosystem services

There are three major supporting ecosystem services that oyster reefs provides. These are (1) habitat provision for fish and invertebrates; (2) augmented fish production; and (3) diversification of the landscape and ecosystem. (Grabowski & Peterson, 2007). These will be discussed below.

The provision of habitat for fish and invertebrates that live in the area is an important supporting ecosystem service that oyster reefs provide (Coen et al., 1999). Compared to other marine habitats, Harding and Mann (2001) state that the diversity and availability of food may be higher in oyster reefs. This shows that oyster reefs can be seen as a productive marine habitat.

Oyster reefs also provide shelter for juvenile fish. By providing habitat for such species, the oyster reefs also indirectly benefit commercial and recreational fishing. This is called augmented fish production. Certain species that live in and around the oyster reefs are predated on by larger species, which can lead to greater populations of these species. Peterson et al. (2003) state that this augmented fish production is not merely due to ‘’adding new fish to the system’’, but due to increasing survival and growth chances for certain fish species that already live in the area. Some of these may be commercially and recreationally fished, which can lead to a higher number of landings of these species (Grabowski & Peterson, 2007). This can in turn benefit tourism by increasing the amount of recreational fishing taking place in the area.

The last supporting ecosystem service that oyster reefs provide is the diversification of the surrounding landscape and ecosystem. Micheli and Peterson (1999) state that an oyster reef can influence landscape-scale processes. For example by providing a corridor between shelter and foraging grounds for organisms that live around the oyster reefs. Furthermore, as just has been discussed, by building an oyster reef in an area, biodiversity can increase because of an oyster reef’s supporting qualities. Behind the reefs, there is more shelter/protection, of which benthic fauna seem to benefit. Hard substrate organisms can be found on oyster reefs (Boersema et al., 2018). This can attract several other species. This leads to a diversification of the corresponding ecosystem (Grabowski & Peterson, 2007).

The extent to which these supporting ecosystem services are provided depends, among other things, on the location of where the oyster reef is located (Grabowski, 2005).

4.2 Provisioning ecosystem services

The provisioning ecosystem service that is provided by oyster reefs is oyster production. Besides functioning as ecosystem engineers, oysters are also harvested for human consumption. As mentioned before, the oysters that are being used in building the oyster reefs are Pacific oysters, *Crassostrea gigas*. In 2017, the Dutch oyster fisheries landed 20.7 million Pacific oysters (Wageningen Economic Research, 2019). This shows that there is a certain demand for these oysters.

4.3 Regulating ecosystem services

The main regulating ecosystem services provided by oyster reefs include (1) carbon sequestration; (2) water quality improvement; and (3) seashore stabilization.

Oyster reefs sequester carbon by extracting and storing it in the calcium carbonate of their shells (Vader, 2014). However, by producing their shells, carbon is released. This makes it unclear whether oyster reefs alone can be seen as a carbon source or sink (Fodrie et al., 2017). Leite Gusmao Junior (2017) showed that bivalve reefs positively affect their surrounding environment, for example by stimulating the growth of algae. This indicates that bivalve reefs plus the effects on their surrounding environment might potentially be a carbon sink. If an oyster reef can be regarded as a carbon sink, they can contribute to battling climate change and to achieving (national) goals to reduce the net amount of greenhouse gasses that are emitted.

Another regulating ecosystem service that is provided by oyster reefs is the improvement of water quality. Oysters are filter feeders, these are organisms that feed upon suspended particles in the water. By doing so, oysters can influence the water quality (Grabowski & Peterson, 2007). This ecosystem service covers several ecosystem processes, e.g. chlorophyll removal, denitrification, turbidity reduction (Grabowski et al., 2012). As a result, oysters help to maintain the overall functioning of the ecosystem (Grizzle, 2006). Furthermore, by improving the water quality, oyster reefs can also contribute to tourism, since a higher water quality often contributes to the scenery of a certain landscape and improves the quality of several activities related to the water quality such as swimming and diving (SwAM, 2012). However, as stated by Dame et al. (2002), the relationship between the water quality and the spatial extent of oyster reef habitat is non-linear. This means that in some situations, a certain threshold has to be crossed in order to the service to be provided. This service also differs per location and therefore, in order to come up with the most precise estimates, one should try to research estimates of this service for the specific area if possible.

The last regulating ecosystem service that is provided by oyster reefs is seashore stabilization. As has been previously mentioned, oyster reefs can protect shores against coastal erosion, reduce hydraulic forces by dissipating wave energy, and increase sediment deposition (EcoShape, n.d.a.) (Scyphers et al., 2011). Oyster reefs are possible to do so, because their structures interact with tidal and wave energy (Meyer et al., 1997). By providing these services, oyster reefs contribute to the stabilization of the seashore. This is also the main goal of the project in the Eastern Scheldt.

4.4 Cultural ecosystem services

Diversification of the landscape and ecosystem can, besides to being a supporting ecosystem service, also be regarded as a cultural ecosystem service. By diversifying the landscape (and ecosystem), the oyster reefs can also affect the aesthetic value of the specific landscape. The aesthetic value of a landscape is determined by people that ‘’make use’’ of the landscape, for example by enjoying the view of that particular landscape (Schirpke, 2016). The Eastern Scheldt is a Natura 2000 area. This often relates to (eco)tourism, since a landscape that has beautiful scenery is often visited by tourists. Davis et al. (2016) analyzed the feelings of Dutch citizens towards nature areas and found that there was a significant overlap between Natura 2000 areas and areas that were highly valued by respondents.

5. Ecosystem service beneficiaries

In order to value ecosystem services, one has to know the beneficiaries of these services. This chapter lists a selection of the ecosystem services provided by oyster reefs, as described in the previous chapter, and their corresponding beneficiaries. The reason that a selection of the ecosystem services is listed, instead of all the ecosystem services provided by oyster reefs, is to only include ecosystem services relevant for this case, and to avoid double counting.

Therefore, the ecosystem service oyster production is not included in this chapter. This is decided because harvesting the oysters will have a negative effect on the long-term persistence of the structure of the reef (Walles et al., 2015a). This will greatly diminish other ecosystem services that are provided. Since the main goal of the project of building these oyster reefs in the Eastern Scheldt is to battle coastal erosion, it would not make sense to include oyster production as a relevant ecosystem service.

The ecosystem service landscape diversification is also not included in this chapter, because of the potential danger of double counting. As has been stated in chapter 4, oyster reefs can affect the aesthetic value of the specific landscape. The aesthetic value of a landscape is determined by people that ‘’make use’’ of the landscape (Schirpke, 2016). The beneficiaries will probably mostly consist of tourists that visit the area, and local residents. This closely relates to the positive effects related to the ecosystem service seashore stabilization, which also positively affects tourism and local residents. Separating the value of the landscape being more diversified from the overall value of (tourist) activities taking place in the area is a complex issue. Due to time and financial constraints, this is not possible for this thesis. It is therefore decided that the ecosystem service landscape diversification will not be included separately in the cost-benefit analysis.

5.1 Ecosystem services with available, relevant information

There are a number of ecosystem services of which relevant information is available concerning the case of constructing oyster reefs in the Eastern Scheldt. These ecosystem services include (1) seashore stabilization; (2) ecosystem diversification; and (3) water quality improvement: denitrification.

5.1.1 Seashore stabilization

The main goal of the project of building oyster reefs in the Eastern Scheldt is to reduce erosion of the tidal flat and contribute to the overall coastal protection. The beneficiaries of this ecosystem service are the people living in the area near the tidal flat, as well as tourists that visit the specific site and the Dutch society as a whole. This could for example involve people that benefit from knowing that the specific area will face less coastal erosion.

The seashore stabilization has a non-consumptive direct use value for these beneficiaries. By reducing erosion of the tidal flats, oyster reefs contribute to minimizing habitat loss for several species that live in the particular area (Reed, 2002). This holds for the Eastern Scheldt, since it is a national park which is rich in biodiversity (Tangelder et al., 2012). For example, bird species such as the *Haematopus ostralegus* and *Numenius arquata* are common visitors that forage in the areas in and around the oyster reefs (Boersema et al., 2018). This contributes to tourism, because the Eastern Scheldt is an area that hosts several touristic activities, with some of them related to local biodiversity (Nationaal Park Oosterschelde, n.d.a.). The area around some of the oyster reefs is also being used by kitesurfers, people going for a walk, and people walking their dog (Boersema et al., 2018). The people that live in the area are positively affected by the stabilization of the seashore. Because by stabilizing the seashore, it is expected that there will be less issues concerning coastal erosion, which in turn might affect adjacent areas. This also affects the (local) government, because costs may have to be incurred to compensate for the erosion.

5.1.2 Ecosystem diversification

As has been discussed, by building an oyster reef in an area, biodiversity can increase because of an oyster reef's supporting qualities (Grabowski & Peterson, 2007). In the Eastern Scheldt, certain bird species forage in the area of some the oyster reefs, mainly the *Haematopus ostralegus* and *Numenius arquata*. Because of rapid colonisation of benthic macrofauna, the area offers potential forage possibilities for other bird species (Boersema et al., 2018). Certain fish species also tend to benefit from an oyster reefs' presence (Peterson et al., 2003). All these activities lead to the ecosystem being more diversified. For this ecosystem service, it is hard to determine the specific beneficiaries, because this ecosystem service supports several other ecosystem services. Concerning valuing this ecosystem service, this service has a non-consumptive direct use value.

5.1.3 Water quality improvement: denitrification

As has previously been mentioned, the ecosystem service water quality improvement covers several ecosystem processes. One of these processes is denitrification.

Denitrification is the process where nitrogen is being removed from the ecosystem (Grabowski et al., 2012). Oyster reefs increase local denitrification rates, thereby enhancing nitrogen removal (Piehler & Smyth, 2011). Russell & Greening (2013) describe that the process of denitrification is not directly enjoyed, consumed, or used by humans. Denitrification therefore has an indirect use value. Before humans can directly enjoy, consume, or use ecosystem services and/or goods that are provided due to denitrification, a certain amount of time has to pass. The beneficiaries of denitrification are the Dutch society as a whole and future generations, because the negative effects of nitrogen are reduced due to its removal.

Grabowski et al. (2011) assessed the long-term economic value of oyster reefs in North Carolina and stated that the value of denitrification accounted for more than half of the total economic value of the ecosystem services provided by the reefs. This shows that denitrification can be an important ecosystem process concerning the provision of ecosystem services by oyster reefs.

5.2 Ecosystem services without available, relevant information

There also are a number of ecosystem services of which relevant information is not available concerning the case of constructing oyster reefs in the Eastern Scheldt. These ecosystem services include (1) carbon sequestration; (2) augmented fish production.

5.2.1 Carbon sequestration

Carbon sequestration is an ecosystem service that has a clear beneficiary, namely the global population. Nowadays, global warming is an important subject of today's debate. The emissions of greenhouse gasses are largely responsible for human-induced warming. Carbon dioxide is a greenhouse gas that is often mentioned with regard to this topic (IPCC, 2014). If an oyster reef can be regarded as a carbon sink, oyster reefs can contribute to reducing the amount of carbon dioxide in the atmosphere. By doing so, oyster reefs can help with battling climate change and meeting (national) goals to reduce the net amount of greenhouse gasses that are emitted. Because greenhouse gasses are not bounded to borders, everyone will be affected by the effects of climate change (IPCC, 2014). Therefore, as just has been mentioned, the global population is the beneficiary of this ecosystem service. Dutch society as a whole could also be seen as a specific beneficiary with regard to meeting (national) net emission targets. This ecosystem service has an indirect use value.

5.2.2 Augmented fish production

As has been mentioned in the previous chapter, augmented fish production can benefit commercial and recreational fishing. By providing habitat, and increasing survival and growth chances for certain species, the number of landings of both commercially and recreationally fished species can be positively affected (Peterson et al., 2003). Logically, a higher number of landings benefits the commercial fishing companies by an increase in their quantities. This increase in quantity benefits the corresponding consumers by an increase in supply. The change in the number of landings depends on the size of the oyster reefs. If a relatively small oyster reef is being constructed, this effect will probably also be small. Peterson et al. (2003) researched the effects of oyster reefs on the fish production in and around these reefs in the southeast United States. They found that an oyster reef enhances the production of fish and large mobile crustaceans by 2,6 kilograms per 10 m^2 of oyster reef per year for the functional lifetime of the reef. Even though this case cannot be directly compared to the Eastern Scheldt, it indicates that there might also be such a number for the Eastern Scheldt.

Just like the commercial fisheries, the recreational fisheries can benefit from augmented fish production by the augmented fish production as a result of the oyster reefs. Van der Hammen et al. (2016) state that in the Netherlands, around 11% of the population is engaged in recreational fisheries. Most of these activities take place in freshwater. Easley & Smith (1992) surveyed recreational fishermen in North Carolina to determine the monetary value of an increase in average catches. They found that a 5% increase would be worth $10 (in 1988 US dollars). Again, even though this case cannot be directly compared to the Eastern Scheldt, it indicates that there might also be such a value for the Eastern Scheldt, because there also are recreational fisheries activities taking place in that area (Nationaal Park Oosterschelde, n.d.b.).

This ecosystem service has an indirect use value, because the augmented fish that are produced due to the oyster reefs' are in turn being caught by commercial and recreational fishers.

6. Scenarios

In order to perform an incremental cost-benefit analysis to compare a breakwater of stones and oyster reefs in terms of cost-effectiveness, different scenarios, or ‘’states of nature’’, have to be developed and described. This chapter will describe these scenarios. Furthermore, the time horizon and discount rate will also be discussed.

The objective of this thesis is to explore whether the construction of oyster reefs is an economically viable alternative to the construction of breakwater of stones. To that avail, the cost-benefit analysis will be performed in incremental terms, and scenarios 2 and 3 will both be compared to the baseline scenario. In this construction, a positive net present value is an indication of the net additional benefits resulting from the use of oyster reefs.

After discussing with Brenda Walles (Walles, pers. comm.), it was decided to use the hypothetical scale of a 1000 meter long, 10 meter wide and 0,5 meter high oyster reef. For the breakwater of stones, a 1000 meter long, 10 meter wide and 0,5 meter high structure is considered. This corresponds with a total surface of 10.000 m^2.

The cost estimates provided in the analysis are average costs and linearity is assumed. This is of course different than marginal costs. Using average costs can lead to an overestimation of the net benefits of relatively small projects. This is a result from combining both fixed and variable costs into an average cost estimate. The costs of a relatively large and a relatively small project both require the same amount of fixed costs, but different amounts of variable costs. This leads to relatively lower average costs for a larger project as compared to a smaller project. Concerning the provision of the benefits, linearity is again assumed due to the available information in this analysis. However in reality, a scale effect often takes place concerning the provision of certain ecosystem services. Koch et al. (2009) state that natural processes and certain ecosystem services as characterized by thresholds. This means that, for example, a ecosystem service is only delivered after a certain threshold is met. This can, among other things, relate to spatial extent. This means that 10.000 m^2 of oyster reef habitat is not the same as 10.000 times 1 m^2 of oyster reef habitat. But because of the information available for this analysis, linearity is assumed.

6.1 Baseline scenario: Breakwater of stones

This scenario is regarded as the business as usual scenario. Stones are used to form a so-called breakwater of stones, which is placed in front of the shore to contribute to battling coastal erosion and fostering coastal protection.

6.1.1 Costs

The total costs that come with this scenario, the breakwater of stones, can be divided into two components.

The first component are the construction costs. These are all the costs that are involved in constructing the breakwater of stones, ranging from material to labour costs. Overhead costs and other costs that are not directly related to the construction of the breakwaters are not included.

The second component are maintenance costs. After a certain amount of time, a breakwater requires maintenance because the stones that form the breakwater are sometimes dislocated over time. This is due to the breakwater's exposure to several pressures, mainly consisting of wave energy. Therefore, the breakwater requires maintenance after a certain time. These maintenance costs consist of material and labour costs.

All costs are calculated excluding value-added tax (VAT).

6.1.2 Benefits

As has been mentioned, the main function of the breakwater of stones to battle coastal erosion and foster coastal protection. The area that lies behind the breakwater is affected by the breakwater, i.e. coastal erosion is reduced and coastal protection is fostered. Breakwaters are used as a measure against coastal erosion all over the world. To maximize its benefits the decision on whether and where to build a breakwater should involve an analysis of shoreline development in the past, but also estimations of its development in the future (Vaidya et al., 2015).

Besides battling coastal erosion and fostering coastal protection, these breakwater of stones generally provide substrate, which can be used by sessile organisms (organisms that anchor to substrate, preventing them for moving about freely (Dworkin et al., 2006)) to settle and by mobile fauna which can use these breakwater as shelter (EcoShape, n.d.a.). Van Ooijen et al. (2017) researched the colonization of different revetment types by seaweed and fauna in a part of the Eastern Scheldt. They found that seaweed and algae were found on the different revetment types. Even though, the revetments are different from breakwaters, they both provide substrate and do somewhat resemble with regard to material and composition. Therefore, this research indicates that these effects might also apply to the breakwaters. However, further, specific research should be done before one extrapolates these results.

6.2 Scenario 2: Oyster reef including only ecosystem services with available, relevant information

This scenario involves constructing an oyster reef as a measure to battle coastal erosion and foster coastal protection. The oyster reef is ''left alone'', which means that no extractive practices will take place, so the reef will not be affected by such practices. The only ecosystem services that are included in this scenario are the ecosystem services with available, relevant information, as described in chapter 5.

6.2.1 Costs

The costs that are will be incurred in this scenario are the construction costs of the oyster reefs. It is assumed that these will be the sole costs in this scenario, since oyster reefs are able to be self-sustaining if the reef is functioning well (Walles et al., 2016). It is assumed that these costs involve all the costs that are involved in constructing the oyster reefs, ranging from (the delivery of) material to actually constructing the reef. Again, overhead costs and other costs that are not directly related to the construction of the reef are not included.

Again, all costs are calculated excluding value-added tax (VAT).

6.2.2 Benefits

In this scenario, only the ecosystem services with available, relevant information are included and regarded as benefits. These are (1) seashore stabilization; (2) denitrification; (3) ecosystem diversification. As a reminder, the comparison between this scenario and the baseline entails establishing whether the provision of these three ecosystem services is different (higher or lower) under scenario 2 versus the baseline. For a description of these ecosystem services, see chapters 4 and 5.

6.3 Scenario 3: Oyster reef including both ecosystem services with and without available, relevant information

This scenario is the same as scenario 2, constructing an oyster reef as a measure to battle coastal erosion and foster coastal protection. However in this scenario I also include ecosystem services for which the available information is of lesser quality or less applicable to the Dutch context.

6.3.1 Costs

The costs in this scenario are assumed to be exactly the same as in scenario 2.

6.3.2 Benefits

The ecosystem services that are included and regarded as benefits are (1) seashore stabilization; (2) denitrification; (3) ecosystem diversification; (4) carbon sequestration; (5) augmented fish production. Again, for a description of these ecosystem services, see chapters 4 and 5.

6.4 Time horizon

An important part of a cost-benefit analysis is choosing a time horizon. The time horizon indicates how many years are being included in the analysis, with regard to the costs and benefits. It is important to thoroughly think about a relevant time horizon for a project, because some costs and/or benefits may differ over the years, or may even only occur after a certain amount of time. Walles et al. (2015a) state that natural oyster reefs of more than 35 years old were found in the Eastern Scheldt. In the information that was obtained concerning the breakwaters it is stated that the lifetime of a breakwater of stones is in principal infinite, provided that maintenance is performed. However, a lifetime of 100 years for the breakwaters is assumed for the project. The time horizon that will be used in this cost-benefit analysis will be 50 years, since 50 years will provide a good overview of the costs and benefits that occur in both scenarios. In order to show how the analysis will change when the time horizon is different, a sensitivity analysis will be performed where the time horizon will both be increased and decreased.

6.5 Net present value

In performing the cost-benefit analysis, the concept of net present value (NPV) will be used to provide a quantitative incremental value of the different comparisons. The NPV is the discounted present value of the sum of all future costs and benefits. The NPV is calculated using the following formula:

$$V_0 = \sum_{t=1}^{T} \frac{c_t}{(1+r)^t}$$

V_0 = net present value (of costs or benefits)
T = time horizon
t = year (with t=0 is the present)
c_t = net costs or benefits in year t
r = discount rate

The NPV will be calculated for each of the costs and benefits that can be quantified within this analysis. Since this cost-benefit analysis will be performed in incremental terms, this will ultimately lead to a NPV in incremental terms for the different comparisons.

6.6 Discount rate

In order to calculate the NPV of the scenarios, a proper discount rate has to be used. The discount rate is a reflection of the time preference of money. This means that the trade-off between consumption today and consumption in the future is captured by the discount rate. A risk-free return on investment and a risk-premium is also taken into account by the discount rate (Horlings et al., 2020). Concerning social cost-benefit analyses in the Netherlands, Werkgroep Discontovoet (2015) advised to reduce the discount rate for public investments to 3 percent. They furthermore advised to use a discount rate of 2 percent for nature, because of an annual relative price increase of 1 percent, due to increased scarcity and limited substitution possibilities. However, for provisioning ecosystem services a discount rate of 3 percent is advised to be used by the Netherlands Environmental Assessment Agency (PBL) (Koetse et al., 2018).

Following this advice, the discount rate for the construction and maintenance costs will be 3 percent. The discount rate for the benefits obtained from the ecosystem services will be 2 percent, except for the commercial benefits obtained from the ecosystem service augmented fish production. Even though this service is not regarded as a provisioning service of oyster reefs, the final benefit that is obtained from this service, an increase in the commercial supply of certain fish species, can be regarded as a provisioning service. Therefore, a discount of 3 percent will be used for this ecosystem service.

7. Results

This chapter will discuss the results of the cost-benefit analysis. The first section provides the estimates of the value of the costs and benefits, quantitatively or qualitatively. The second section compares the baseline scenario (breakwater of stones) and scenario 2 (oyster reefs including only ecosystem services with existing, high quality information applicable to the Netherlands). The third section compares the baseline scenario (breakwater of stones) and scenario 3 (oyster reefs including both ecosystem services with and without available, relevant information). All of these comparisons are in terms of the net present value (NPV). This is the discounted value of the sum of all future costs and benefits in each scenario.

7.1 Estimates of costs

7.1.1 Costs related to breakwater of stones

Construction costs

A breakwater of stones can be built in several locations and for different purposes. There are several breakwater of stones in the Netherlands in different locations. For this cost-benefit analysis, the construction costs of different breakwaters of stones in the Western Scheldt will be used. The Western Scheldt is close to the Eastern Scheldt and comparable with regard to the location. In general, the goal of the breakwaters of stones that are built in the Western Scheldt is to recover nature by reducing the speed of the water flow to create intertidal flats. Using these cost data, calculating construction costs per m^3 of breakwater of stones turns out to be €223,99 in 2019 euros. Correcting for inflation[1], this corresponds with a value of €229,81 per m^3 of breakwater of stones. Using this number to calculate the construction costs of the 1000 meter long, 10 meter wide and 0,5 high breakwater of stones, leads to total construction costs of €1.149.064,50.

Maintenance costs

A breakwater of stones requires maintenance, because the stones that form the breakwater are sometimes dislocated over time due to several pressures. The breakwaters that are used in this cost-benefit analysis are expected to require maintenance once in five years. Based on the cost information related to the breakwater of stones in the Western Scheldt, which was also used to calculate the construction costs, it was calculated that the breakwater of stones in this case requires maintenance for 416,67 m^3 every five years. Based on personal communication with the contact person concerning the cost information of the breakwaters, it was decided to use the construction costs per m^3 as measure for the costs per m^3 of maintenance. This means that every five years, maintenance costs of €95.755,37 are included.

7.1.2 Costs related to oyster reefs

[1] https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83131NED/table?ts=1586176304714

Construction costs

As has been stated earlier, several oyster reefs on different intertidal flats in the Eastern Scheldt are currently being researched. Costs estimates of four of these reefs were provided by Brenda Walles (Walles, pers. comm.). These reefs differ in length, width and height. The location of the hypothetical case that is regarded in this thesis closely resembles the location of these reefs, since all are built on intertidal flat in the Eastern Scheldt, Therefore, the average cost per m^3 based on the cost estimates of these reefs was used to provide a cost estimate per m^3 for this case. This average cost per m^3 of these reefs was €142,42 in 2012 euros. Correcting for inflation, this corresponds with a value of €161,34 in 2020 euros. Using this number to calculate the construction costs of the 1000 meter long, 10 meter wide and 0,5 high oyster reef, leads to total construction costs of €806.705,97.

7.2 Estimates of benefits

7.2.1 Benefits related to breakwater of stones

Seashore stabilization

The main benefit of a breakwater of stones is that it stabilizes the seashore by reducing coastal erosion and contributing to overall coastal protection (Vaidya et al., 2015). This service is immediately provided once the breakwater of stones has been constructed. In this cost-benefit analysis, it is assumed that the breakwater of stones and oyster reef provide seashore stabilization to the same extent (Walles, pers. comm.). This means that the affected areas and parties by this ecosystem service will also be the same for both the breakwater of stones and oyster reef.

Ecosystem diversification

As has been described in chapter 6, a breakwater of stones generally provides hard substrate for sessile organisms to settle and as shelter for mobile fauna (EcoShape, n.d.a.). Furthermore, as has also been stated in chapter 6, the research by Van Ooijen et al. (2017) indicates that seaweed and algae might also be present on breakwaters. Firth et al. (2013) compared artificial intertidal coastal defence structures with intertidal natural habitats concerning biodiversity. They found that these artificial structures do indeed provide habitat for several species. However, natural habitats are able to support more biodiversity due to relatively more environmental heterogeneity and water-retaining features (Firth et al., 2013).

It is assumed that this service is immediately provided once the breakwater of stones is constructed. Furthermore, it is assumed that the provision of this ecosystem service is constant over time. It is very hard to quantify and monetize the effects of such an ecosystem service as ecosystem diversification. This will include several measures, such as, among others, estimating the marginal changes in the ecosystem concerning species, biomass and so on, and calculating the corresponding value that beneficiaries attach to these changes in the ecosystem. Due to several constraints, this is not possible for this thesis. I will therefore refrain from quantifying and monetizing this ecosystem service. This means that this ecosystem service will be valued qualitatively. To come to the point, a breakwater of stones will increase the diversification of the ecosystem in the specific area as compared with unstructured mud bottom.

Augmented fish production

This ecosystem service closely relates to the ecosystem service ecosystem diversification. As just has been mentioned, hard substrate and structures generally support biodiversity (EcoShape, n.d.a.)(Van Ooijen et al., 2017). This indicates that fish production and landings by both commercial and recreational fisheries might increase due to the breakwater's presence. No quantitative data has been found on this particular ecosystem service. This service will therefore be valued qualitatively. Based on the literature, it is assumed that the presence of a breakwater of stones will augment fish production as compared to unstructured mud bottom. Further research should indicate the actual extent of this ecosystem service concerning a breakwater of stones.

7.2.2 Benefits related to oyster reefs

Seashore stabilization

The main goal of constructing oyster reefs in the Eastern Scheldt is to reduce coastal erosion and foster overall coastal protection. Just like the scenario involving breakwater of stones, this ecosystem service is immediately delivered once the oyster reef is constructed (Walles et al., 2015b). As has previously been mentioned, in this cost-benefit analysis, it is assumed that the breakwater of stones and oyster reef provide seashore stabilization to the same extent. However, oyster reefs are able to grow vertically, whereas a breakwater of stones cannot. Rodriguez et al (2014) even showed that oyster reefs can outpace sea-level rise. Walles et al. (2015a) researched three long-living oyster reefs (>30 years old) in the Eastern Scheldt and found that these reefs vertically grew 7.0 – 16.9 mm of shell material per year. This indicates that assuming that the seashore stabilization service provided by the breakwater of stones and an oyster reef is equal might lead to an underestimation with regard to the oyster reef over time. However, for simplicity it is still assumed that the breakwater of stones and oyster reef provide seashore stabilization to the same extent.

Ecosystem diversification

It is assumed that this service will immediately be provided once the oyster reef is constructed. This has been decided based on Chowdhury et al. (2010), and on personal communication with Brenda Walles (Walles, pers. comm.). Furthermore, it is assumed that the provision of this ecosystem service is constant over time.

Oyster reefs provide hard substrate that can be used by different kinds of organisms for different purposes. Boersema et al. (2018) also found that hard substrate species that are common in the Eastern Scheldt were present on oyster reefs, such as the periwinkle (*Littorinidae*), mussels (*Mytilus edulis*), and various crabs (*Carcinus maenas, Hemigrapsus takanoi* and *Porcellana platychelles*). Chowdhury et al. (2020) researched the effects of oyster reefs on benthic and fish fauna on an eroding intertidal flat in the southeastern coast of Bangladesh. They found that the reefs enhanced both abundance and biomass of several species, such as benthic macrofauna, fish and different mobile macro-invertebrates. Even though their research was done in Bangladesh, they stated that their study provided evidence that oyster reefs provide several ecological benefits. In combination with the findings by Firth et al. (2013), this shows that oyster reefs provide ecosystem diversification to a higher extent than a breakwater of stones does.

As previously already has been mentioned, it is very hard to quantify and monetize the effects of the ecosystem service as ecosystem diversification, and that it will be valued qualitatively. In conclusion, like a breakwater of stones, oyster reefs will increase the diversification of the ecosystem in the specific as compared with unstructured mud bottom. However, the extent to which this ecosystem service is provided is greater as compared to a breakwater of stones (Firth et al., 2013) (Chowdhury et al., 2020).

Denitrification

As has been discussed briefly in chapter 5, denitrification is the process where nitrogen is being removed from the ecosystem (Grabowski et al., 2012). Oyster reefs increase local denitrification rates, thereby enhancing nitrogen removal (Piehler & Smyth, 2011).

In order to obtain an estimate concerning denitrification by oyster reefs in the Eastern Scheldt, results provided by Piehler and Smyth (2011) were used. They researched denitrification in different coastal habitats in North Carolina in the US, one of these being oyster reefs. After doing so, they came up with yearly denitrification rates in kilograms per year per acre for each of these habitats. It is assumed that these denitrification rates also apply to the Eastern Scheldt. By subtracting the amount of nitrogen that was initially removed in an intertidal flat (without an oyster reef) from the amount of nitrogen that was removed by oyster reefs, the enhanced amount of nitrogen removal due to oyster reefs was calculated. They calculated that an oyster reef on an intertidal flat enhanced denitrification by 109 kilogram per acre per year. By conversing acre to m^2, this corresponds with 0,27 kilograms of nitrogen removed per m^2 of oyster reef per year (assuming linearity).

Besides denitrification in the reef itself, oyster reefs also enhance denitrification in surrounding sediments. Piehler & Smyth (2011) found enhanced denitrification rates in sediments up to 1 meter away from the reefs. Walles et al. (2015b) also found that oyster reefs affect sediments that are largely beyond the boundary of the reef. In the Eastern Scheldt, bivalve reefs are able to modify and affect the surrounding ecosystem up to several hundred meters around the reefs (Van der Zee et al., 2012; Van de Koppel et al., 2015). This might also affect denitrification rates in surrounding sediments. However, these effects are based on observational data and statistical modelling only (Leite Gusmao Junior, 2017). Therefore, the conservative estimate of 1 meter will be used to calculate the augmented denitrification in surrounding sediments. This likely underestimates the reef's actual potential to enhance denitrification in surrounding sediments, which was also mentioned by Brenda Walles (Walles, pers. comm). Because if, for example the actual effect of the reef on surrounding sediments turns out to be up until 50 meter, this will be a considerable area for a 1000 meter long reef.

The monetary value of denitrification was calculated using the environmental prices handbook by De Bruyn et al. (2018). They calculated environmental prices by combining three kinds of methods. These methods enabled De Bruyn et al. (2018) to define physio-chemical relationships between different interventions, such as between emissions and midpoint impact, as well as between midpoint impact and endpoints. This was followed by describing the relationships between emissions and endpoint impacts, and the effect of these emissions on humans, animals, plants and materials. At last, *''valuation techniques establishing a financial relationship between endpoint impacts and the changes in economic welfare resulting from altered availability of the endpoint* (De Bruyn et al. 2018, p.45)*''* were used to determine the environmental price. See chapter 4 of De Bruyn et al. (2018) for a more elaborate explanation of the calculation of these environmental prices. By using these methods, they calculated an environmental price of total nitrogen emissions to water of €3,11 per kilogram of emission in 2015 euros. Correcting for inflation, this corresponds with an environmental price of €3,29 per kilogram of emission in 2020 euros. Multiplying this environmental price with the total amount of kilograms of nitrogen removed per year by a m^2 of oyster reef, results in a value of €0,89 per m^2 of oyster reef per year. In calculating the value of denitrification by the oyster reef in this case, linearity was assumed, which was also assumed by Grabowski et al. (2011). This means that 10.000 m^2 of oyster reef would provide €8.942,98 in denitrification services yearly.

However, as we have just discussed, the surrounding sediments up to 1 meter away of the oyster reef will also be taken into account. For a 1000 meter long and 10 meter wide reef, this corresponds with an area of 2.032,57 m^2 of sediments that have enhanced denitrification rates due to the oyster reef's presence. The value per m^2 of this enhanced denitrification in the surrounding sediments is assumed to also be €0,89 per m^2. This means that the total yearly denitrification value in the surrounding sediments is €1.817,72. This corresponds with a total yearly value of denitrification (including both the reef and sediments) of €10.760,70 (in 2020 euros).

Denitrification takes place once living oysters settle on the reef. The Pacific oyster reproduces in late summer, between July and September (Walles et al., 2016). This means that if you construct the reef in the winter, denitrification will take place after one year. As just has been discussed, the reef also affects surrounding sediments concerning denitrification, so the denitrification process might start earlier. It is therefore assumed that the benefits obtained from denitrification will not immediately be delivered, but after one year (in year 2) once the reef has been constructed.

Carbon sequestration

As has been described in chapter 4, it is unclear whether oyster reefs can be seen as carbon sinks or sources (Fodrie et al., 2017). This makes it very hard, maybe even impossible, to quantify the effects of this ecosystem service. It is therefore assumed that oyster reefs alone have a net effect of zero concerning carbon sequestration. Leite Gusmao Junior (2017) showed that bivalve reefs positively affect their surrounding environment, for example by stimulating the growth of algae. This can support carbon sequestration in surrounding sediments. This indicates that bivalve reefs plus the effects on their surrounding environment might potentially be a carbon sink. Therefore, in this cost-benefit analysis, the effects of the oyster reef on surrounding sediments concerning carbon sequestration is also taken into account. Just like with denitrification, it is assumed that surrounding sediments up until 1 meter are positively affected concerning carbon sequestration. Because no relevant data is available concerning this ecosystem service, this benefit will be valued qualitatively.

The process concerning carbon sequestration and release by oyster reefs starts once oysters settle and grow. So if the constructed oyster reef consists of living oysters, this process starts immediately. However, if you also use dead oyster shells, this process starts later. The studied reefs in the Eastern Scheldt consisted of both living and dead oyster shells. So in order to reduce the risk of overestimating, it is assumed that this service starts providing after one year once the reef has been constructed. Furthermore, it is assumed that the provision of this ecosystem service will be constant during the lifetime of the reef.

As just has been mentioned, this ecosystem service will be valued qualitatively. The oyster reef alone has a net effect of zero concerning carbon sequestration. But because it is assumed that that surrounding sediments up until 1 meter are positively affected concerning carbon sequestration, the total net effect of an oyster reef concerning this ecosystem service is positive. Further research should try to quantify this ecosystem service concerning oyster reefs. By quantifying this ecosystem service, a monetary value could potentially be attached. This could e.g. assist decision-making concerning coastal management.

If one manages to obtain data on carbon sequestration by oyster reefs (in the Eastern Scheldt), there are several ways to calculate the monetary value of carbon sequestration. For example, Horlings et al. (2020) used two approaches to estimate the value of carbon sequestration by biomass in the Netherlands, both representing avoided damage costs. The first approach they used was to use the social cost of carbon (SCC). The SCC is *''the change in the discounted value of economic welfare from an additional unit of CO_2-equivalent emissions* (Nordhaus 2017, p. 1518)*''*. The second approach they used was looking at a CO_2 emissions target that was defined by a specific policy, and calculating the costs of achieving this policy. This leads to an estimate of a carbon price. By using this approach, the contribution of an ecosystem and/or ecosystems to achieving the policy target in monetary terms is calculated (Horlings et al., 2020). Naturally, the carbon price that is obtained by using the second approach is likely to differ between countries, because of different policies concerning CO_2 emissions. Horlings et al. (2020) state that the second approach seems preferable as compared to using the SCC. One of the explanations is that the second approach is more dependent on the level of political ambition concerning CO_2 emission targets. For a more elaborate explanation of this preference, see chapter 4.5 of Horlings et al (2020).

Augmented fish production

As has been mentioned in chapter 4, oyster reefs are able to augment fish production by providing habitat, and increasing survival and growth chances for certain species (Peterson et al., 2003). No sufficient data on the potential of this ecosystem service in oyster reefs in the Eastern Scheldt, or in a comparable case, has been found. Hancock & zu Ermgassen (2019) state that it is hard to quantify the actual enhancement of fish production by oyster reefs, because the total value does not only consist of the enhancement of juvenile fish species, but the effect of the reef on species that associate with the reef at later life history stages should also be taken into account.

The work by Peterson et al. (2003) has been influential concerning the development of the quantification of augmented fish production by oyster reefs. They researched the effects of oyster reefs on the fish production in and around these reefs as compared to sedimentary bottoms in the southeast United States. They found that an oyster reef enhances the production of fish and large mobile crustaceans by 2,6 kilograms per 10 m^2 of oyster reef per year for the functional lifetime of the reef. Grabowski & Peterson (2007) converted this to a monetary value by using dockside landing values of all the species that were researched by Peterson et al. (2003). They calculated that the monetary value of augmented fish production by 10 m^2 of oyster reef is $3,70 (in 2007 US dollars) per year. Converting this to 2007 euros by using the 2007 exchange rate between US dollars and euros[2], this corresponds with a value of €2,70 in 2007 euros. Correcting this number for inflation in the Netherlands leads to a value of €3,34 in 2020 euros. This corresponds with a value of €0,33 per m^2 of oyster reef, assuming linearity concerning the provision of this ecosystem service. For an oyster reef with a total area of 10.000 m^2, the total yearly value of this service would be €3.340.

This quantitative estimate provided by Peterson et al. (2003) is the only estimate concerning this ecosystem service that was obtained during this thesis. However, this estimate does not provide a comparable estimate for the case of constructing an oyster reef in the Eastern Scheldt. For example, the different fish species that were being used to calculate the value of this ecosystem service do not live in the Eastern Scheldt. But in order to provide a value for this ecosystem service in this case, the value provided by Peterson et al. (2003) will be used, using a 50%, 100%, and 150% estimate. However, one must take into account that these values are purely used as an indication, and should not be regarded as representative numbers for the Eastern Scheldt. Further research on this ecosystem service in the Eastern Scheldt should be performed to provide reliable estimates. Using the 50%, 100%, and 150% estimates lead to yearly values of €0,17; €0,33; and €0,50 per m^2 of oyster reef habitat, respectively.

Based on zu Ermgassen et al. (2016a) (updated in zu Ermgassen et al. 2018), it was decided that during the first five years after construction of the reef, the value of augmented fish production is 50% of its full potential. After these 5 years, it is assumed that the value of the service has reached its full potential (€0,33 per m^2 using 100% estimate) and will be constant. This means that, using the 50%, 100%, and 150% estimates, the yearly values during the first 5 years will be €835,45; €1.670,91; and €2.506,36 respectively for 10.000 m^2 of oyster reef habitat.

The above values only include commercial fishing. But as was mentioned in chapter 5, this ecosystem service is also likely to benefit recreational fishing. As has previously been stated,

[2] https://data.oecd.org/conversion/exchange-rates.htm

Easley & Smith (1992) surveyed recreational fishermen in North Carolina to determine the monetary value of an increase in average catches. They found that a 5% increase would be worth $10 (in 1988 US dollars). Again, even though this case cannot be directly compared to the Eastern Scheldt, it indicates that there might also be such a value for the Eastern Scheldt, because there also are recreational fisheries activities taking place in that area (Nationaal Park Oosterschelde, n.d.b.). Furthermore, surveys among recreational fishers in North Carolina in the United States in 1997-2001 found that catch rates were augmented by 39.1% due to oyster reefs' presence, as compared with unstructured mud bottom (Grabowski et al., 2001). This is a lot more than the 5% increase that was used by Easley & Smith (1992). More data is needed to provide an estimate of the value of this ecosystem service for recreational fishers in the Eastern Scheldt. And again, these estimates are not directly comparable to this case. If both commercial and recreational fishers are competing for the same fish species, the numbers could also turn out differently (Grabowski et al., 2011). Due to all of these considerations, the provision of this ecosystem service with regard to recreational fishing will be valued qualitatively. In conclusion, recreational fishers are also assumed to benefit from the oyster reef's presence.

Zu Ermgassen et al. (2016b) describe a model that provides estimates concerning the enhancement of fish production due to an oyster reef's presence. Currently, there are only estimates available for certain areas in the US. However, such a model might also be applicable to other sites, outside of the US, once data is present. This might help quantifying the enhancement of fish production due to an oyster reef's presence for other projects, supporting corresponding management decisions.

7.3 Baseline scenario- Breakwater of stones versus Scenario 2- Oyster reef including only ecosystem services with available, relevant information

This section compares the baseline scenario, a breakwater of stones, with scenario 2, an oyster reef including only ecosystem services with available, relevant information in incremental terms. It will provide a comparison of a 1000 meter long, 10 meter wide and 0,5 meter high oyster reef, and a 1000 meter long, 10 meter wide and 0,5 meter high breakwater of stones. Once again, the value that is presented in this section is an incremental value. This means that a positive NPV is an indication of the net additional benefits resulting from the use of an oyster reef instead of a breakwater of stones. Whereas a negative NPV is an indication of net losses.

Construction costs

Construction costs are present in both scenarios. The construction costs of 1 m^3 of breakwater of stones are €229,81; whereas the costs of 1 m^3 of oyster reef are €161,34. Thus the incremental difference is €68,47 per m^3.

Maintenance costs

Maintenance costs are only involved in the breakwater of stones scenario. As has been described, every five years maintenance costs of €95.755,37 are included. However, after the last five years, no maintenance costs are included, because it would not make sense to include maintenance costs at the end of the lifetime of the breakwaters of stones.

Seashore stabilization

As has been described in section 7.1, it is assumed that the seashore stabilization service provided by the breakwater of stones and the oyster reef is equal. In other words, the incremental difference for this service is 0.

Ecosystem diversification

As has been described in section 7.1, both the breakwater of stones and the oyster reef increase the diversification of the ecosystem. But it was shown that oyster reefs provide ecosystem diversification to a higher extent than a breakwater of stones does. This means that an oyster reef will provide net benefits with regard to ecosystem diversification as compared to a breakwater of stones. Thus, if a monetary value for this service can be obtained, including it in the analysis will lead to a higher, positive NPV.

Denitrification

The benefits obtained from denitrification is only obtained in the scenario involving the oyster reef. As has been stated, the total yearly value of denitrification (including both the reef and sediments) is €10.760,70.

Net Present value

Using the above values, the NPV was calculated. Using the 50-years time horizon, the NPV is €1.112.167,49. As figure 3 and 4 indicate, a large share of the total net benefits are obtained when the construction takes place. This is a result of the oyster reefs involving lower construction costs. Furthermore, figure 4 shows that every five years, there is an increase in annual net benefits, as compared to the previous year. This is due to the fact that the breakwater of stones requires maintenance, whereas the oyster reef does not.

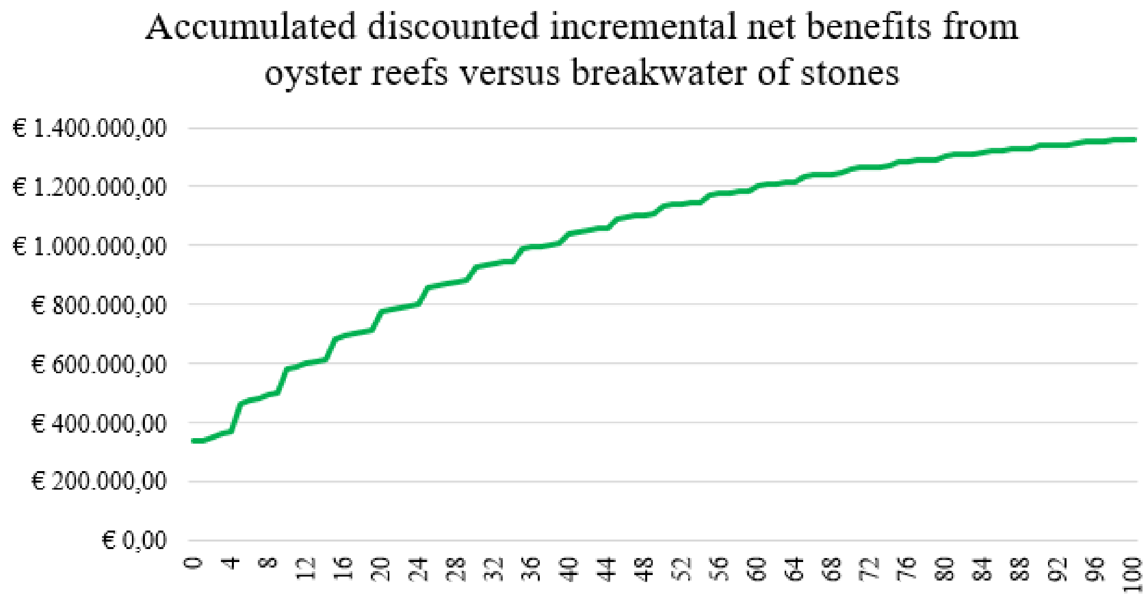

Figure 3. *Accumulated discounted incremental net benefits from oyster reefs versus breakwater of stones (baseline scenario versus scenario 2 vertical axis represents value, whereas horizontal axis represents time in years).*

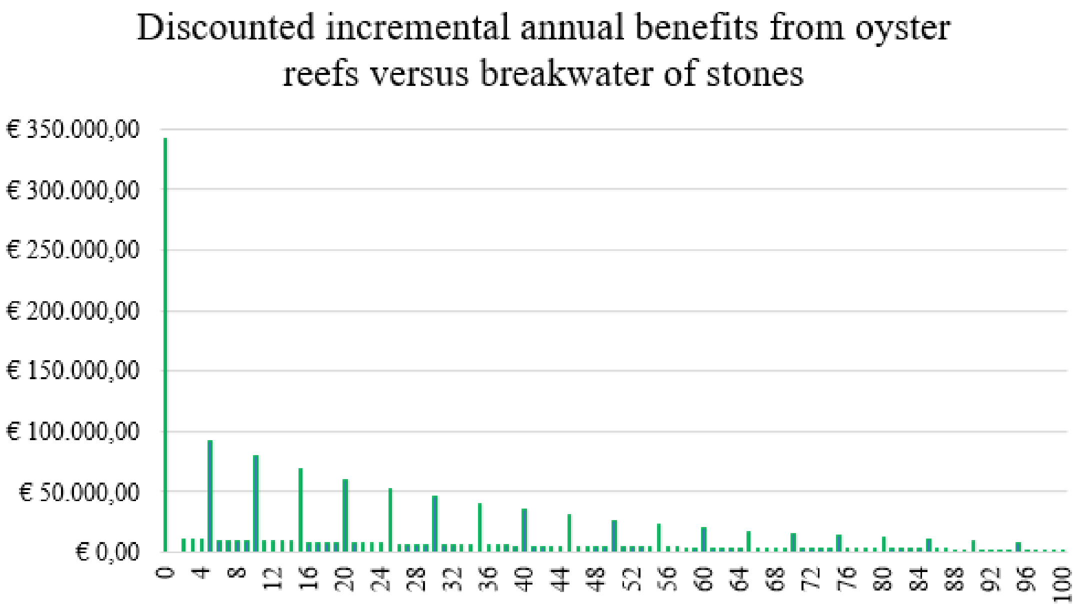

Figure 4. *Discounted incremental annual net benefits from oyster reefs versus breakwater of stones (baseline scenario versus scenario 2, vertical axis represents value, whereas horizontal axis represents time in years).*

Sensitivity Analysis

Changing the time horizon leads to a different NPV but the overall results remain the same. For example, using a 25-year time horizon leads to a NPV of €810.224,51 of incremental net benefits in favour of oyster reefs. The NPV is lower when a 25-year time horizon is used instead of a 50-year time horizon. This is easily explained, because in this analysis each year provides positive net benefits of oyster reefs as compared with the breakwater of stones (as can be seen in figure 3). Decreasing the time horizon therefore also decreases these total net benefits, leading to a lower NPV.

Increasing the time horizon also leads to a different NPV. For example, using a 100-year time horizon leads to a NPV of €1.360.511,64. The NPV is higher as compared to when a 50-year time horizon is used. This is again easily explained, since, as just has been explained, increasing the time horizon leads to an increase in total net benefits, which results in a higher NPV.

Changing both discount rates (3% for construction and maintenance costs and 2% for benefits obtained from ecosystem services) leads to different NPVs. If both discount rates are increased by 1% point, so 4% and 3%, the NPV for a 50-year time horizon is €975.091,97. This is a lower NPV as compared to when discount rates of 2% and 3% are used.

If both discount rates are decreased by 1% percentage point, so 2% and 1%, the NPV for a 50-year time horizon is €1.296.106,96. This is a higher NPV as compared to when discount rates of 2% and 3% are used.

These changes in NPVs are also easily explained. This again relates to the fact that each year provides positive net benefits of oyster reefs as compared with the breakwater of stones. Increasing the discount rates will lead to a lower present value of this benefits, resulting in a lower NPV. Whereas decreasing the discount rates does the exact opposite, namely increasing the present value of the benefits, leading to a higher NPV.

7.4 Baseline scenario- Breakwater of stones versus Scenario 3- Oyster reef including both ecosystem services with and without available, relevant information

This section compares the baseline scenario, a breakwater of stones, with scenario 3, an oyster reef including both ecosystem services with and without available, relevant information incremental terms. The same scales as in section 7.3 will be used. Once again, the value that is presented in this section is an incremental value. This means that a positive NPV is an indication of the net additional benefits resulting from the use of oyster reefs instead of a breakwater of stones. Whereas a negative NPV is an indication of net losses.

The values for the construction and maintenance costs, seashore stabilization, ecosystem diversification, and denitrification are the same as in section 7.2.

Carbon sequestration

The benefits from the ecosystem service carbon sequestration are only obtained in the scenario involving the oyster reef. As stated in section 7.1, the total net effect of an oyster reef concerning this ecosystem service is assumed to be positive (taking the effects on surrounding sediments into account). This means that the oyster reef provides net benefits concerning carbon sequestration as compared to the breakwater of stones. Thus, if a monetary value for this service can obtained, including it in the analysis will lead to a higher, positive NPV.

Augmented fish production

The benefits from the ecosystem service augmented fish production are obtained in both scenarios. However, quantitative data concerning the scenario involving the oyster reef. The yearly values during the first 5 years for the 50%, 100%, and 150% estimates are €835,45; €1.670,91; and €2.506,36 respectively. After 5 years, these values will be constant at €1.670,91; €3.341,81; and €5.012,72 respectively.

If monetary values can be obtained concerning the provision of this service concerning the breakwater of stones, the NPV is likely to decrease. Furthermore, if monetary values can be obtained concerning the effect of this service on recreational fisheries, the NPV will increase if this value is higher for the oyster reefs as compared with the breakwater of stones, whereas it will decrease if it is the other way around.

Net Present Value

Using the above values, the NPV was calculated. Using the 50-year time horizon, the NPV is €1.190.499,27 using the 100% estimate for the augmented fish production service. Using the 50% or 100% estimates for this service leads to a NPV of €1.151.333,38 and €1.229.665,16. This shows that the NPV decreases when a lower estimate for the benefits of this service are used, whereas a higher estimate leads to a higher NPV, which is straightforward.

Figure 4 again provides an overview of the accumulation of annual net benefits. Because the differences between the 50%, 100%, and 150% are relatively small, only the 100% is included in this graph. Just like in section 7.3, figure 5 and 6 indicate that a large share of the total net benefits are obtained when the construction takes place, and that every five years, there is an increase in annual net benefits as compared to the previous year due to the maintenance costs.

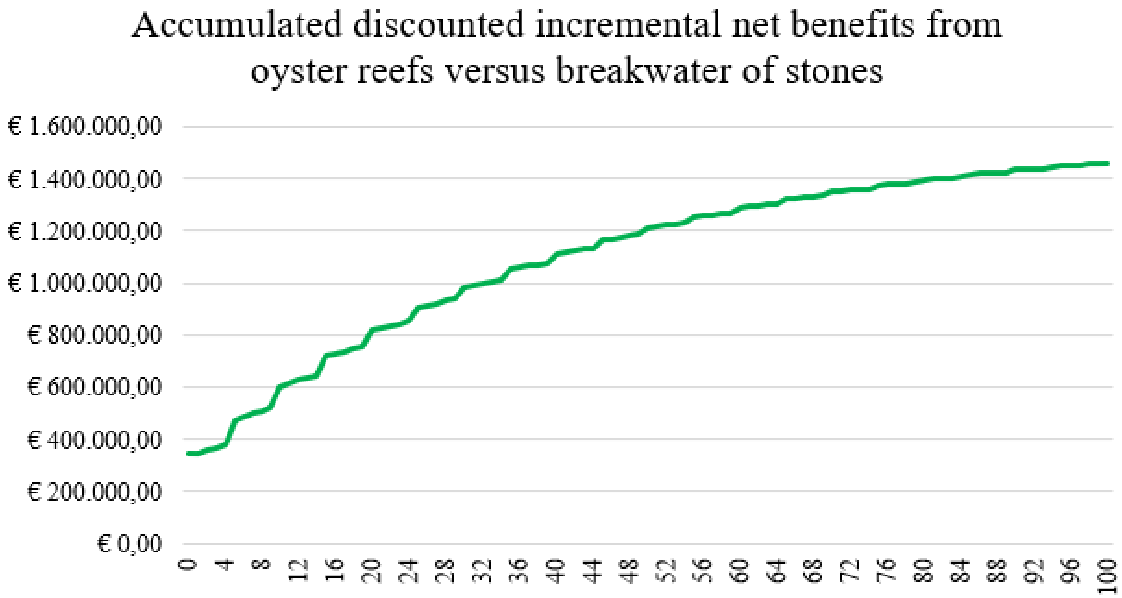

Figure 5. *Accumulated discounted incremental net benefits from oyster reefs versus breakwater of stones (baseline scenario versus scenario 3, vertical axis represents value, whereas horizontal axis represents time in years).*

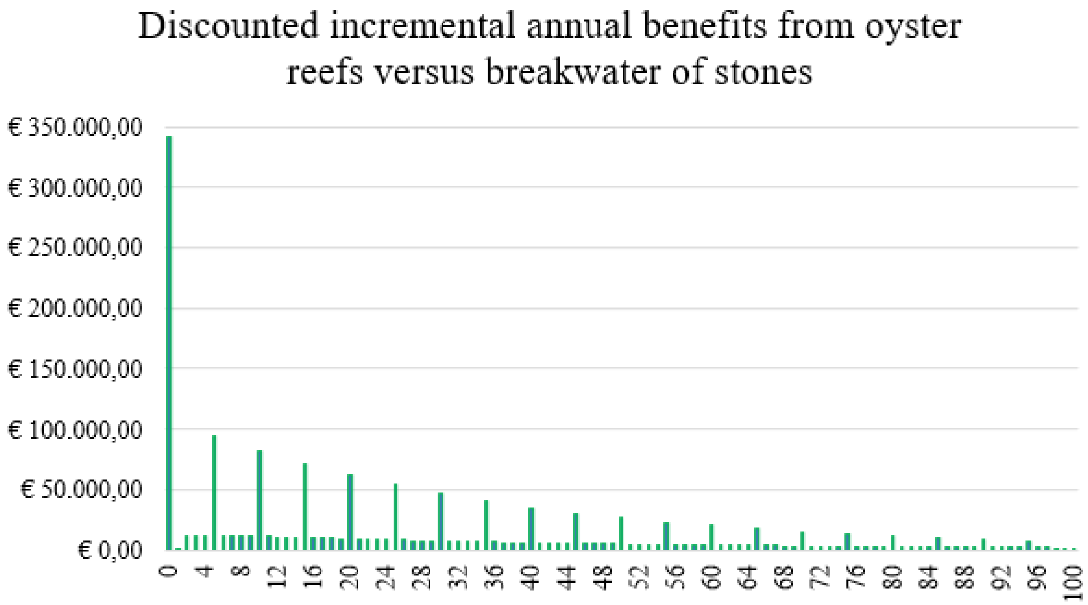

Figure 6. *Discounted incremental annual net benefits from oyster reefs versus breakwater of stones (baseline scenario versus scenario 3, vertical axis represents value, whereas horizontal axis represents time in years).*

Sensitivity Analysis

Changing the time horizon leads to different NPVs. For example, using a 25-year time horizon leads to NPVs of €835.494,12; €860.763,72; and €886.033,33 using the 50%, 100% and 150% estimates for augmented fish production, respectively. The NPVs are lower when a 25-year time horizon is used instead of a 50-year time horizon.

Increasing the time horizon also leads to different NPVs. For example, using a 100-year time horizon leads to NPVs of €1.409.484,31; €1.458.456,98; and €1.507.429,66 using the 50%, 100% and 150% estimates for augmented fish production, respectively. The NPVs are higher as compared to when a 50-year time horizon is used. The explanation of these changes is the same as in section 7.3.

Changing both discount rates (3% for construction and maintenance costs and 2% for benefits obtained from ecosystem services) leads to different NPVs. If both discount rates are increased by 1% point, so 4% and 3%, the NPVs for a 50-year time horizon are €1.007.267,40; €1.039.442,82; and €1.071.618,24 using the 50%, 100% and 150% estimates for augmented fish production, respectively. These are lower NPVs as compared to when discount rates of 2% and 3% are used.

If both discount rates are decreased by 1% percentage point, so 2% and 1%, the NPVs for a 50-year time horizon are €1.344.674,98; €1.393.243,00; and €1.441.811,02 using the 50%, 100% and 150% estimates for augmented fish production, respectively. These are higher NPVs as compared to when discount rates of 2% and 3% are used. The explanation of these changes is again the same as in section 7.3.

8. Discussion

This thesis provided a description of EbA, ecosystem services (provided by oyster reefs) and an incremental cost-benefit analysis involving a breakwater of stones and an oyster reef as a measure against coastal erosion. One of the goals of this thesis was to also include the monetary value of certain ecosystem services that are provided in the scenarios. It turned out that there was less quantitative information available for the ecosystem services than I would have hoped. This led to a qualitative valuation of several ecosystem services. I would have preferred to be able to quantitatively value more ecosystem services to provide a more representative NPV in the cost-benefit analysis. However, this thesis can be used as input for further research concerning the monetary valuation and/or a cost-benefit analysis with regard to this topic, by indicating where further research is necessary.

This lack of quantitative information also resulted in several assumptions that had to be made concerning the ecosystem services. Firstly, the assumption of equal provision of seashore stabilization by the breakwater of stones and oyster reef. Secondly, the qualitative valuation of ecosystem diversification based on literature, whereas studying an actual site will probably provide a more accurate estimation. Thirdly, the assumption that denitrification rates in the reefs in the US are equal to the reefs in the Eastern Scheldt. These rates may actually differ in reality. Fourthly, the assumption that oyster reefs have a positive net effect concerning carbon sequestration, due to the effects on surrounding sediments. Fifthly, the assumption about the extent up until surrounding sediments will be affected by the oyster reef's presence. The actual effect might be different, maybe even a lot greater. At last, the assumptions concerning the ecosystem service augmented fish production. For the breakwater of stones, a qualitative valuation based on the literature had to be made. Data from the US concerning this ecosystem service with regard to oyster reefs were used, even though these are not representative for the Eastern Scheldt. The actual value might be very different.

Furthermore, linearity and constancy was assumed concerning the calculation of both the costs and benefits. However, as has been described, the provision of ecosystem services are often not linear and sometimes a certain threshold has to be met before the service will be delivered. The values that have been calculated might therefore be different from the actual value. Further research should try to clarify the scale effects concerning the benefits provided by oyster reefs. Using average costs also likely leads to an overestimation of the net benefits of relatively small projects, as has been explained in chapter 6.

These assumptions potentially lead to a less accurate estimate of the provision and/or value of the ecosystem services. Further research should clarify these topics/issues, which lead to a better understanding of the ecosystem and its provided services. This ultimately leads to more accurate estimates concerning both scenarios.

Another point that is important to take into account, is that breakwaters are relatively less sensitive to where they can be constructed, whereas a location needs to meet several criteria for oyster reefs to be able to (sustainably) grow. This has to be taken into account when comparing different options as measures against coastal erosion. In this thesis, the location of hypothetical case was assumed to be suitable for both the oyster reef and the breakwater of stones. In reality, this has to be researched to determine the feasibility of the different measures.

At last, the time horizon that has been chosen also affects the outcome of the cost-benefit analysis. In this situation however, increasing or decreasing the time horizon does not lead to a different outcome concerning a positive or negative NPV, due to the fact that each year provides positive net benefits of oyster reefs as compared with the breakwater of stones, because no quantitative data was obtained concerning the benefits of the breakwater of stones. If one manages to obtain relevant, representative quantitative data concerning these benefits, changing the time horizon might have a different effect on the outcome of the analysis.
The same situation applies for the discount rate, increasing or decreasing the discount rate leads to a lower or higher NPV in this analysis, respectively. Again, if one manages to obtain relevant, representative quantitative data concerning these benefits, changing the discount rate might have a different effect on the outcome of the analysis.

9. Conclusion

The objective of this thesis was to explore whether an oyster reef or a breakwater of stones is a more cost-effective measure against coastal erosion. This was done by performing an incremental cost-benefit analysis of an oyster reef as compared to a breakwater of stones, including tangible and non-tangible costs and benefits.

Oyster reefs can be used as an EbA measure to battle coastal erosion. In order for oyster reefs to be used as such a measure in the Eastern Scheldt, the project team should focus on trying to create a support base for the project, in order to make sure that the project will be implemented on a larger scale, and be part of a larger overall policy framework (Walles, pers. comm). Oyster reefs provide several ecosystem services. In this analysis, the ecosystem services seashore stabilization, ecosystem diversification, denitrification, carbon sequestration, and augmented fish production were included. Some of these ecosystem services lack sufficient, relevant quantitative data concerning oyster reefs in the Eastern Scheldt. Quantitative estimates for denitrification and augmented fish production were found. However, the estimates for the ecosystem service augmented fish production are not representative for the Netherlands/Eastern Scheldt. They have been included using 50%, 100%, and 150% estimates to provide an indication of the potential value of this service, but further research should try to come up with representative estimates.

Two comparisons were involved in the cost-benefit analysis. The first comparison compared the breakwater of stones with oyster reefs, including only ecosystem services with available, relevant information. Whereas the second comparison compared the breakwater of stones with oyster reefs, including both ecosystem services with and without available, relevant information. This ultimately led to a NPV for both comparisons. Using a 50-year time horizon, the NPV for the first comparison was €1.112.167,49. For the second comparison, the NPV was €1.190.499,27 using the 100% estimate for the augmented fish production service. Using the 50% or 100% estimates for this service leads to a NPV of €1.151.333,38 and €1.229.665,16. This shows that including the value for augmented fish production does not make that big of difference. In both comparisons, the NPV is clearly positive. So based on this analysis, it is recommended to use oyster reefs to battle coastal erosion in the Eastern Scheldt. However, as has already been mentioned, there was a lack of quantitative data in this analysis. Therefore, this analysis should not be used to justify the use of oyster reefs to battle coastal erosion in the Eastern Scheldt. This analysis should rather be regarded as explorative research concerning the costs and benefits of using a breakwater of stones or oyster reefs to battle coastal erosion, indicating where further research is needed. In order to perform a cost-benefit analysis that can actually justify the use of oyster reefs, one needs more (quantitative) data to come up with representative values and ultimately a NPV.

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