Costs and benefits of adapting to climate change at six meters below sea level

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Abstract

Climate change increases the vulnerability of low-lying coastal areas. Careful spatial planning can reduce this vulnerability. An assessment framework aimed at reducing vulnerability to climate change enables decision-makers to make better informed decisions about investments in adaptation to climate change through spatial planning. This paper presents and evaluates an approach to assess adaptation options, with the use of cost-benefit analysis. The assessment framework focuses on the selection and identification of adaptation options, and identifies the best available information on incremental costs and benefits. The approach is applied to an area located at six meters below sea level in the Netherlands. Adaptation options relating to spatial planning, such as flood proof housing and adjusted infrastructure, are identified, and when possible, quantified. Results show that cost-benefit analysis assists in the selection of adequate adaptation options. The assessment framework is applicable to other low-lying coastal areas around the world that suffer from the impacts of climate change.

Keywords: climate change, adaptation, spatial planning, assessment framework, cost-benefit analysis

1. Introduction

The changing climate increases the vulnerability of societies around the world. The fourth assessment report of the IPCC (Parry et al., 2007) defines vulnerability in the context of climate change as “the degree to which a system is susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes”. The core concepts that determine the vulnerability of a system are the exposure, sensitivity and adaptive capacity of a system (Adger et al., 2005; Adger, 2006; Smit and Wandel, 2006; Swart and Raes, 2007). Implementation of adaptation measures reduces the vulnerability of a society to the effects of climate change. Adaptation, in this context, is defined as “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (Parry et al., 2007). Various types of adaptation are distinguished including *reactive* or *proactive* (anticipatory), and *autonomous* or *planned* adaptation (Fankhauser et al., 1999; Smit et al., 1999; Smit et al., 2000). This paper focuses on planned anticipatory adaptation, where policymakers play an important role in taking well-considered policy decisions which are aimed at reducing vulnerability to climate change (Klein et al., 2003; Parry et al., 2007). Climate robust designs that reduce the vulnerability of societies to known and uncertain impacts of climate change are needed to ‘climate proof’ spatial planning. Climate robust adaptation options are designs that perform well under different climate change scenarios and related uncertainties.

Consideration of climate change impacts in spatial planning increases the adaptive capacity of a country (IPCC, 2007). At the local government level spatial planning has a key role to play in anticipatory adaptation (Bulkeley, 2006; Wilson, 2006). Tol et al. (2008) point out that climate change should be considered in the design phase, because “retrofitting existing infrastructure is more expensive than designing it to be more flexible or more robust”. Within Europe, the ESPACE project (European Spatial Planning: Adapting to Climate Events), developed a decision support tool, which provides spatial planners with guidance in assessing how climate change might affect development options over the next 100 years or more (ESPACE, 2008). The EU-funded ADAM project (Adaptation and mitigation strategies: Supporting European Climate Policy) also focuses on the roles for policy in adaptation, and states that governments play a major role in “modification of infrastructures and of spatial plans in response to climate impacts” (CEPS, 2008). In the Netherlands adaptation to climate change is closely related to spatial planning because the Netherlands is a densely populated country where adjustments of policies related to economic development have spatial consequences. The strong link between water management and spatial planning in the Netherlands provides opportunities for adaptation to climate change (De Vries, 2006). The Dutch government launched the Climate changes Spatial Planning Research Programme (CcSP) and Adaptation Programme for Spatial Planning and Climate (ARK) to provide input for the adaptation strategy of the Netherlands.

As adaptation of spatial planning to climate change entails both costs and benefits, it is important for decision-makers to assess the effectiveness of adaptation options, when they decide how to spend a limited government budget. Adaptation needs to be implemented in an efficient and effective way. A framework that includes an adaptation assessment and cost-benefit analysis can identify and prioritise climate robust adaptation options to reduce vulnerability. In the literature frameworks and adaptation assessments are presented that support decision-makers in their decisions regarding adaptation to climate change. Adaptation assessments aimed at the identification and evaluation of adaptation options are presented for specific sectors, such as the water and health sector (Rosenzweig et al., 2007; Ebi and Burton, 2008). However, the planning sector does not always clearly involve stakeholders in the decision-making process. In addition, several studies conduct a cost-benefit analysis in the context of climate change, specifically related to the assessment of mitigation policies (Bürgenmeier et al., 2006; Tol and Yohe, 2007; Hof et al., 2008). Very few studies, however, assess adaptation policies (Leary, 1999; De Bruin et al., 2009), and as Tol et al. (2008) point out there is “empirical knowledge lacking about how adaptation would work in reality”.

In this paper we develop an assessment framework for the design and evaluation of adaptation options. This framework aims to support planning decisions regarding the implementation of adaptation strategies to reduce vulnerability to climate change. The framework structures scientific information for the planning of adaptation and requires active participation of planners and stakeholders. This framework should not be seen as a step-by-step technical exercise to inform and legitimise top-down decisions, but rather as an approach towards facilitating the exchange of bottom-up ideas, to stimulate dialogue for reaching common ground (Goosen, 2006). In addition, this paper aims at contributing to the existing lack of empirical knowledge by presenting costs and benefits of adaptation to climate change. The framework is applied to a planning process for the development of an area in the western part of the Netherlands. The results of the cost-benefit analysis indicate that efficient and effective adaptation options can be implemented, but not *all* adaptation options would result in an efficient investment.

The paper is organised as follows. Section 2 presents the general assessment framework, with a special focus on the role of and the issues relating to conducting a cost-benefit analysis (CBA) of climate robust spatial planning. Section 3 introduces the case study, and section 4 shows and discusses the results of the CBA of a set of four adaptation options relevant for the spatial planning of an area in the south-western part of the Netherlands. Section 5 discusses the theoretical and practical applicability of CBA related to spatial planning, and concludes.

2. Methodology

2.1 The assessment framework

Assessing climate change adaptation options requires an assessment framework that describes the planning process to be followed. The assessment framework applied to climate robust spatial planning includes the following phases: (1) Scenario phase, (2) Design phase, (3) Evaluation phase, and (4) Selection phase (Figure 1).

In the *Scenario phase* the effects of climate change in the area under consideration are identified. The IPCC climate change scenarios or available national climate change scenarios are translated to the local level, where primary effects of climate change are determined. In addition, the primary climate change effects are used to determine the secondary effects. For instance, the primary effect of increased peak precipitation has a secondary impact on agriculture if flooding occurs. In the *Design phase*, the reference situation (business as usual case) is described for the local area, which considers the existing spatial planning. The climate change scenarios are projected onto the reference situation to gain better insight into the specific effects of climate change for the area. In addition adaptation options are identified in close consultation with stakeholders, such as local water boards, local policy-makers and nature organisations. In the *Evaluation phase* the direct and indirect effects of the adaptation options are assessed and where possible quantified and monetarized. A social cost-benefit analysis (SCBA) is conducted for the identified costs and benefits of the adaptation options. The results of the SCBA are further analyzed through a sensitivity analysis, to consider the effects of such variables as the discount rates and the time horizon on the results. As a final step the results of the SCBA and sensitivity analysis are discussed with all decision-makers and stakeholders regarding the implications on the economic efficiency of the new spatial planning and the impacts of climate change as identified in the scenario and design phase. Through the *Iteration* and *revision* process, the results of the evaluation phase are revised in a circular process with updated climate change scenarios, updated costs and benefits information, and reflection on the designs. In the *Selection phase* a selection of the adaptation options is made by the decision-makers.

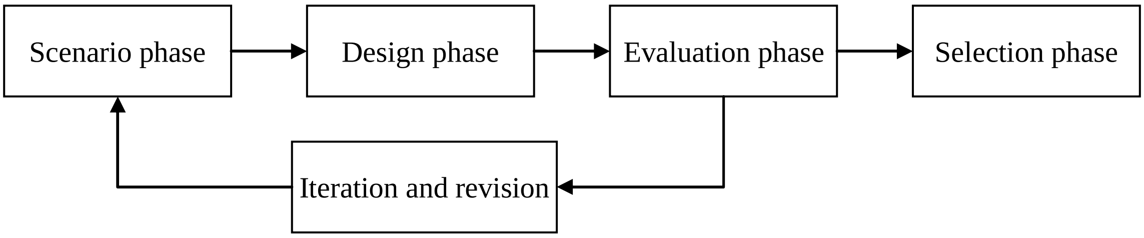

Figure 1. Schematic representation of the assessment framework

2.2 Costs and benefits of adaptation of spatial planning

In the evaluation phase of the assessment framework the adaptation options are evaluated with the use of social cost-benefit analysis (SCBA). SCBA assesses and compares the total welfare effect of alternative projects, by considering not only the direct costs and benefits but also the indirect or external effects of the alternatives. Through communication of the steps made to derive the SCBA results, thereby presenting intermediate results and a sensitivity analysis, decision-makers gain better knowledge about how the results of the assessment are derived. The specification of the effects on the different stakeholders involved increases the transparency in the decision-making process. Given the timing of the costs and benefits, as well as the discount rate, the present value of the benefits and costs can be determined. The net present value (NPV) is calculated by the formula

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t}$$

where B_t denotes the benefits and C_t denotes the costs of an adaptation option in year t, r the discount rate and T the time horizon of the project. The decision rule is to go ahead with the project if its NPV is positive or, in the case of competing projects, with the projects that show the highest NPV. A positive NPV indicates that the project delivers a surplus of benefit over cost (Perman et al., 1999). As spatial planning focuses on the long term impacts of climate change, the effect of climate change on development needs to take the following 100 years or more into consideration. Rouwendal and Van der Straaten (2007) indicate that in the application of cost-benefit analysis to spatial planning the external effects of spatial planning and the public good characteristic of spatial planning should be specifically taken into account. In this paper the net present value is calculated over a time horizon of 100 years, with a discount rate of 2.5%, as indicated by Dutch regulations for spatial planning. The Dutch government changed the recommendation of the risk-free discount rate for SCBA from 4 to 2.5% in 2007 (Ministry of Finance, 2007).

In the context of climate change a cost-benefit analysis becomes more complicated when uncertainty needs to be taken into account. Uncertainties of climate change pose new challenges for decision making and for assessing policy options. These uncertainties in combination with irreversible effects may affect the optimal choice of the policy instrument, the optimal policy intensity and the optimal timing of implementation (Pindyck, 2007). If adaptation options are implemented too early, irreversible investment costs are made. On the other hand if the policies are implemented too late, possible irreversible damages may occur. Uncertainties of climate change related to economic and ecological uncertainty (Pindyck, 2000) might be resolved through acquiring more information, e.g. through further research and learning. Irreversible investment decisions should only be undertaken now if expected NPV exceeds the opportunity costs of keeping the investment option open (Dixit and Pindyck, 1993).

3. Application to the Zuidplaspolder, the Netherlands

The assessment framework as introduced in section 2 is applied to a case study area situated in the low-lying part of the Netherlands. The Zuidplaspolder (ZPP) is an area located in the south-western part of the Netherlands. A large part of the polder is located at six meters below sea level. In 2006 the national government adopted the national spatial strategy (Nota Ruimte, 2006) in which specific areas in the western part of the Netherlands were designated for further economic development. The Zuidplaspolder was selected for urban development, focused on new residential, commercial and further agriculture development (greenhouse horticulture).

Figure 2. Location of the pilot projects in the Zuidplaspolder[1] (Source: Xplorelab (2008))

The province of Zuid-Holland together with several municipalities, non-governmental organisations and the water authority of Schieland and the Krimpenerwaard made a master plan for the spatial development of the area. For the period 2010 - 2020 the plan includes the construction of 15 000 - 30 000 houses, the creation of 125 hectares of commercial area, 280 hectares greenhouse of horticulture area, 500 hectares of ecological development, space for water storage and infrastructure improvements. In addition, a project was launched to investigate the urgency of ‘climate proofing’ the new spatial development of the Zuidplaspolder[2]. The aim of the project was to provide input for developing the polder in such a way that future inhabitants of the polder suffer a minimum impact of the possible effects of climate change.

The project followed the assessment framework as described in section 2.1. In phase 1 (Scenario phase) the long-term effects of climate change were identified for the province of Zuid-Holland and narrowed down to the Zuidplaspolder (ZPP). Climate change scenarios, based on Parry et al. (2007) and KNMI (2006), served as inputs to determine the effects of climate change on the ZPP (see Table 1 for more details of the estimates of the KNMI scenarios for 2050 and 2100). This study focused on the climate scenarios W+. A study was performed in 2007 to investigate the local impacts of the climate scenarios for the province of South Holland (Van den Berg et al., 2007). This study was used to identify the relevant effects of climate change on the ZPP. The most important impacts are: the effects of flooding from sea-level rise and/or river discharge; the effects of flooding from precipitation; the effects of water shortages related to droughts, the effects of salinization; and the effects of temperature rise (heat waves).

Table 1. Description of KNMI climate change scenarios

Year		2050		2100	
Climate scenarios[a]		W	W+	W	W+
Global temperature rise (°C)		+2	+2	+4	+4
Change in air circulation patterns		No	Yes	No	Yes
Winter	Average temperature change (°C)	+1.8	+2.3	+3.6	+4.6
	Average precipitation change (%)	+7	+14	+14	+28
Summer	Average temperature change (°C)	+1.7	+2.8	+3.4	+5.6
	Average precipitation change (%)	+6	-19	+12	-38
Sea level	Absolute rise (cm)	20-35	20-35	40-85	40-85

Source: KMNI (2006)

[a] KNMI climate scenarios for 2050 and 2100 (high estimates) compared with 1990 (W: warming without air circulation patterns; W+: warming with more westerly winds in winter and easterly winds in summer).

In phase 2 (Design phase), based on the effects of climate change as identified in phase 1, adaptation options were identified with the aim to ‘climate proof’ the ZPP. The alternatives are strongly interlinked with the already existing development plans and master plan, namely the Interregional Development Vision (ISV, 2006), and the Inter-municipality Development Plan (ISP, 2006). The identified adaptation options were defined through workshops, consultations with stakeholders and design sessions with various experts. The options relate to water safety, water-related nuisance, water shortage and heat stress caused by climate change.

The workshops and design sessions yielded a large number of adaptation options (over 50 plans were identified). Next, the long-list of options was reduced to four concrete proposals for adaptation for climate proofing in specific areas within the Zuidplaspolder. These four adaptation options were included in the SCBA: (1) Water storage for housing and greenhouse development in the northern part of the Zuidplaspolder, (2) Climate robust ecological network (entire area Zuidplaspolder), (3) Climate robust design of the residential area of Nieuwerkerk Noord, and (4) Climate robust design of a residential area of Moordrecht. Figure 2 shows the location of the adaptation options in the Zuidplaspolder. The reference situation is the current master plan for the area. Table 2 presents the adaptation options, and which specific impacts of climate change are addressed by the adaptation options.

Table 2. Adaptation options identified for the Zuidplaspolder

	Adaptation option	Specification	Climate change impacts
1.	Water storage for housing and greenhouse development in the Zuidplas Noord	Water storage in the urban area	Flooding & Impacts on water resources
		Water storage in the agricultural area	Flooding & Impacts on water resources
2.	Climate robust ecological network	Creation of corridors	Impacts on ecology
3.	Climate robust design of a residential area Nieuwerkerk Noord	Raising the entire area through sand suppletion	Flooding
		Raised infrastructure	Flooding
4.	Climate proof housing Moordrecht Noord	Flood proof construction of houses	Flooding

Adaptation option 1 aims at creating areas for water storage, to prevent periodical damage to crops and property caused by heavy rainfall in the northern part of the Zuidplaspolder. This area should accommodate the development of 800 houses and 280 hectares of greenhouse horticulture. Two alternatives were designed to overcome a flood event by creating sufficient storage capacity for water in the urban area (alternative 1) or in the agricultural area (alternative 2). Figure 3 shows an impression of the water storage in the Zuidplas Noord.

Figure 3. A sketch of water storage in a mixed urban-agricultural area in the Zuidplas Noord (Xplorelab, 2008)

Adaptation option 2 deals with the adaptation of the ecological network in the Zuidplaspolder. The effects of climate change on nature in the polder relate to issues such as drought, more intense precipitation and an increase in the average temperature. Adaptation option 3 focuses on the urban expansion of Nieuwerkerk Noord is the largest development within the Zuidplaspolder. In total around 1800 houses will be developed. Two alternatives are considered in the cost-benefit analysis: (1) reference situation: raising the area of the development of 1800 houses by sand suppletion to a level where no damage occurs in case of a flood event, and (2) raised infrastructure: the area itself is not raised but instead protected by a raised road, which functions as a dike. In addition, adaptation option 4 aims to climate proof the expansion of the municipality of Moordrecht with 250 houses in one of the lowest parts of the Zuidplaspolder. Different types of houses were designed, varying from houses with, for example, water tight glass walls or houses on top of dikes (see Figure 4).

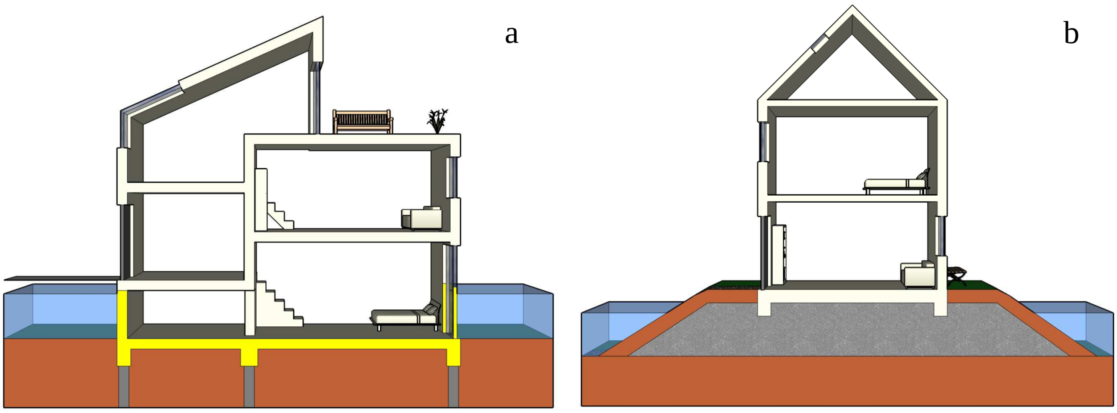

Figure 4. Flood proof house with glass walls (a) and Flood proof house on a dike or elevated area (b) (Xplorelab, 2008).

In phase 3 (Evaluation phase) the monetary value of the relevant effects is specified and used as input for the cost-benefit analysis of the adaptation options. The direct effects of an adaptation option involve investment costs (construction, purchase of land, development) and avoided damage costs of climate change. Indirect effects include changes in landscape, such as increased access to nature areas. External effects of an adaptation option include the effect of the option on other areas, such as increased flooding of neighbouring areas, due to measures taken in the ZPP. Furthermore, it is important to identify which stakeholders suffer the costs or receive the benefits. The cost-benefit analysis requires that in a quantitative assessment of the adaptation options all the related costs and benefits are identified. This was, however, not possible for all the identified effects related to climate proof spatial planning, such as synergy or competition effects between the options, or the effect on mitigation efforts of the adaptation options. As not all effects can be assessed with certainty, such as the effects on soil and air quality these should be evaluated qualitatively. This will affect the final outcome of the cost-benefit analysis and should be discussed in the sensitivity analysis of the results. Through iteration the results of phase 3 are assessed in a circular process to reach the optimal outcome of the cost-benefit analysis. Due to time constraints it was however not possible to repeat the scenario phase with updated climate change scenarios, reflect on the identified adaptation options or update the costs and benefits.

In phase 4 (Selection phase) a final selection of the adaptation options is made by the decision-makers.

4. Results of the social cost-benefit analysis of the case study

In the evaluation phase of the assessment the total welfare effects of the adaptation options were identified. The adaptation options were assessed in more detail and compared with the reference situation, with specific focus on: investment costs, avoided damages, and valuation of water and nature. The reference situation is the master plan for the spatial development of the ZPP. The following sections provide a more detailed analysis of the identified direct and indirect effects, a specific description of the four adaptation options and the related costs and benefits and presents a summary of the results of the SCBA for the four adaptation options.

4.1 Direct effects

The costs of direct effects include direct costs of flood protection measures (sand suppletions, creation of raised infrastructure) and the purchase of land to create additional water storage or nature areas. Direct benefits include avoided damages, where total avoided damage costs equal the discounted sum of the expected annually avoided damage costs over a period of 100 years. The expected annually avoided damage costs is the product of the avoided damage costs times the probability of damage each year. The probability of an extreme rainfall event is set at once per 100 years; the probability of flood event from a dike breach along the Hollandsche IJssel is set at once per 10 000 years, based on the Flood Protection Act (2006). The direct investment costs take place in period 1, while the benefits (avoided damages) are spread over a period of 100 years. The investment costs and avoided damages of the adaptation options were quantified by specialized research institutes (Delft University of Technology, TNO, Dura Vermeer and Deltares).

4.2 Indirect effects

The monetary values for nature and water values associated with alternative land use types were estimated specifically for the ‘Hotspot Zuidplaspolder’ project. The large-scale survey of almost 2 500 households living in or close to the ZPP was performed by Brander (2008) to elicit local residents’ preferences for the relevant landscape characteristics. Respondents were asked to choose between pairs of alternative future landscape designs. Landscape designs were represented in maps together with information on the level of additional municipal tax associated with each design. Information on the trade-offs that respondents made between landscape characteristics and additional tax was used to estimate average household willingness to pay (WTP) for each landscape characteristic.

Table 3 presents the willingness to pay estimates for additional water rich and wetland areas, public access to these areas, and for the avoidance of raised infrastructure. For additional units of water rich area, households are on average willing to pay € 13 per km^2 per year in additional municipal tax. This value was aggregated over the total number of households in municipalities in the vicinity of the ZPP, namely Gouda, Moordrecht, Nieuwerkerk aan den IJssel, Waddinxveen, and Zevenhuizen-Moerkapelle. Together these municipalities contain 60 341 households and this gives a total annual WTP for each additional hectare of water rich area of almost € 8 000 per year. The estimated WTP for additional area of wetland is considerably lower. Average annual household WTP for an additional km^2 of wetland is around € 1. Aggregating this across the total number of households gives a total annual WTP for each additional hectare of wetland area a value of just above € 600 per year. Regarding public access to nature areas (water rich and wetland), average annual household WTP for open access is € 28.30. On an aggregate level this is over € 17 000 per hectare per year. Regarding public preferences to avoid raised infrastructure, average annual household WTP to avoid raised roads and railway lines is around € 18 per year, the total annual WTP is just over € 1 million.

Table 3. Willingness to pay (WTP) for landscape characteristics in the ZPP

	Annual WTP per household [a]		Total annual WTP	
Water area	13	€/km^2	8 000	€/ha
Wetland area	1	€/km^2	600	€/ha
Public access	28	€/km^2	17 000	€/ha
Avoidance of raised infrastructure	18	€	1 060 000	€

[a] Brander (2008)

4.3 SCBA of adaptation option 1: Water storage for housing and greenhouse development in the Zuidplas Noord

The costs and benefits were identified for the reference situation (where no additional adaptation measures are proposed) and the alternatives. The following costs and benefits were included in the SCBA: (1) avoided damage costs to crops and property, (2) increased quality of the urban area due to presence of water and nature, and (3) costs of creating an additional area of water and nature in the housing area.

4.3.1 Avoided damage costs

The hydrological SOBEK model is used to calculate potential damage in the area in case of extreme rainfall events under the climate scenarios developed by KNMI (2006). The model predicts that a rainfall event with an expected frequency of once per 100 years would cause flooding in an area of 14 hectares. This flood would cause damage in the area which is mainly used by greenhouse agriculture. Previous flood events in similar areas reported average economic damage per hectare of around € 230 000 (Van der Bolt and Kok, 2000). Using these reported damages as an indicator, the extreme event would cause a damage of € 3.2 million. The net present value of the expected avoided damage costs is estimated at € 1.2 million.

4.3.2 Increased quality of the urban area

Brander (2008) shows an annual willingness to pay of € 8 000 per additional hectare of water and a WTP of € 17 000 per hectare of accessible public park in the direct vicinity of the houses. The area for water storage consists of 3 hectares of water and 20 hectares of public parks that will periodically inundate. This implies that the net present value of the area (at a discount rate of 2.5% for a period of 100 years) is estimated at € 13.7 million.

4.3.3 Costs of creating an additional area of water and nature in the urban area

The cost of creating the area required for water storage is estimated simply by taking the approximate land prices in the area (around € 300 per m^2) times the area size. This leads to a price of € 69 million. The area is developed directly alongside the houses and is used and owned by the inhabitants of the area. It is thus privately owned land which is shared by the people living directly around the area. According to the plan, this privately owned area can be sold for about half the price of the land. In that case costs are estimated at € 35 million.

In summary, the SCBA shows that the costs exceed the benefits considerably. The NPV of the benefits (€ 1.2 million avoided damage and € 13.7 million increased WTP) do not weigh up against the costs of creating the area (€ 35 million).

4.4 SCBA of adaptation option 2: Climate robust ecological network

Xplorelab (2008) identified the adjustments needed for adaptation of the ecological network in the polder, which includes the further development and management of nature in the polder to deal with issues such as drought and more intense precipitation. The costs of acquisition, development and management of additional nature areas for the Zuidplaspolder have been calculated by experts from the Province Zuid-Holland. An additional green area of 93 hectares will be created. The total costs are € 9.4 million, which include capitalized management costs for the area. The benefits of additional nature area have been estimated through the choice experiment results described in section 4.2 (Brander, 2008) which show an annual willingness to pay of € 17 000 per hectare per year of free accessible nature areas in the ZPP and this results in an annual benefit of € 1.6 million.

The net present value of this adaptation option are € 50 million, i.e. net benefits exceed the net costs of the option. The relatively high level of the willingness to pay for free access to nature by households might be explained by the lack of accessible nature areas in this particular part of the Netherlands. It is important to realise that the stakeholders who suffer the burden of the costs of this adaptation option do not receive the direct benefits of the option. Overall, the NPV of the benefits of creating additional nature areas outweigh the costs of creating these areas, therefore making this adaptation option a socially efficient investment.

4.5 SCBA of adaptation option 3: Climate robust design of the residential area of Nieuwerkerk Noord

The costs and benefits of the urban expansion are calculated for the two alternatives (the reference situation and the raised infrastructure alternative). The following costs and benefits are considered: (1) avoided damage costs in case of a flood event, (2) costs of flood protection measures (raising the area through sand suppletion, costs of raised infrastructure), and (3) costs and benefits of creating an additional area of water and nature in the housing area.

4.5.1 Avoided damage costs

The residential area of Nieuwerkerk Noord is situated in the lower part of the polder. In case of a flood event, the area could be damaged. A simulation of such a flood event showed that a potential damage would occur of € 78 million (Xplorelab, 2008). Hydrologists estimate the chance of such an event to occur at once per 10 000 years; based on the expected frequency of the maximum water level in the river to be reached. The dikes are designed to cope with water levels up to this maximum level (of 2.70 m above mean sea level). This leads to a expected net present value for avoided damage costs of € 0.3 million (at a 2.5% discount rate, 100 years time horizon).

4.5.2 Costs of flood protection measures

The area has weak soil stability due to the fact that it has a high organic soil content (peat soils). Depositing sand to raise the area compresses the peat soils and as a result the deposited sand sinks. A study by Geodelft (Xplorelab, 2008) showed that, in order to raise the area by approximately 1.50 meter, about 6 meter of sand is required. The process of subsidence will take at least two years to stabilize. At an average price of € 10 per m^3 of sand, the costs of raising the area is estimated at € 38.2 million. For the raised infrastructure alternative, these costs of raising the area are avoided. Instead, costs have to be made to construct the houses on unstable soils with relatively high water levels. Also there are additional costs for constructing the new road, which can function as a dike. These costs have been estimated at € 11.4 million by Dura Vermeer (a large building and engineering company in the Netherlands). The costs of the raised infrastructure alternative are therefore estimated to be € 26.8 million lower (€ 38.2 million versus € 11.4 million) than the reference situation (Xplorelab, 2008).

4.5.3 Costs and benefits of creating an additional area of water and nature in the housing area

For the raised infrastructure alternative, it was calculated that an additional 3.5 hectares of open water needs to be created for water storage. This area of water is needed to be able to store peak rainfall. In the reference situation, this extra reservation for water is not necessary because more water can be stored in the ditches (because the building area has been lifted, the difference between soil surface and water levels in the ditches increases). The extra storage for water implies that either a lower total number of houses can be built or the same amount has to be built on a smaller area. The costs (in terms of avoided benefits from the property development) have been estimated at a net present value of € 10 million. On the other hand, the water area will have benefits. Brander (2008) shows an annual willingness to pay of € 8 000 per additional hectare of water. Based on this study an annual benefit of € 28 000 is estimated.

In summary the raised infrastructure alternative has considerably lower development costs, than raising the area, mainly due to the fact that a large volume of sand is required to ‘lift’ the area. The required volume is large because of the low stability of the (peat) soils. This type of development (where sand is deposited and houses are built on top) is standard practice and is not performed as a flood risk prevention measure, and referred to as the reference situation.

The raised infrastructure alternative reduces the costs of development by approximately € 27 million.

4.6 SCBA of adaptation option 4: Climate proof construction of the 'Moordrecht' area

The simulation of a flood event (Xplorelab, 2008) showed that a flood in the 'Moordrecht' area potentially incurs € 12 million worth of damage. In case of such a flood event, the maximum inundation depth in the Moordrecht area was estimated at 1.30 m. As stated in the previous section, the chance of such an event occurring has been estimated at once per 10 000 years. This leads to a net present value for avoided damage costs of € 0.07 million (at a 2.5% discount rate, 100 year time horizon). These avoided damage costs are very low compared to additional costs for enhancing flood safety. Nevertheless, the Delft University of Technology developed a flood-proof design for the area (Xplorelab, 2008). A key element in this design plan is that the new houses are designed to sustain 1.60 m water level. The flood simulation model estimated a maximum water depth of 1.30 m, but adding to this an additional 30 cm for wave height, the area was designed for a maximum water depth of 1.60 m.

4.6.1 Costs and benefits

An estimation of costs and benefits was difficult to make because innovative techniques are proposed in the flood proof plan that had not been tested. These innovative techniques are assumed to be more costly than conventional building techniques. On the other hand, costs will be lower for the preparation of the area, namely raising and flattening the area with sand. The Delft University of Technology estimated the additional costs (as compared to conventional development of 250 houses) at approximately a present value of € 20 million (Xplorelab, 2008). Because this is a much higher figure than the reduced expected damage (€ 0.07 million) the plan has a negative NPV.

4.7 Summary

The results of the SCBA for four adaptation options are summarized in Table 4. The numbers represent an 'order of magnitude' of the costs and benefits needed to climate proof the Zuidplaspolder as the quantification of some direct and indirect effects was not possible. When considering the NPV results of the four adaptation options, it is clear that not all adaptation options are an efficient investment, as the costs of investment exceed the benefits of the avoided damages. When focused on ‘climate proofing’ the total area of the Zuidplaspolder, however, the costs and benefits of all the presented adaptation options should be taken into account, which results in a positive net present value (€ 47 million). The main factors are the avoided costs of sand suppletion to elevate the area. For example, for adaptation option three (Climate robust design of the residential area of Nieuwerkerk Noord), the alternative with only raised infrastructure reduces the costs of construction with about € 27 million. Also the benefits from creating additional nature and water areas were considerable, based on the outcome of the study by Brander (2008). Somewhat surprisingly, the benefits from reduced flood risk and avoided damage in the case of flood events are completely outweighed by the costs of the adaptation measures. The damage costs of such an event can be high, up to € 200 million for the Zuidplaspolder (Xplorelab, 2008). The chances of flood events occurring in this part of the Netherlands are, however, very small (in the order of once per 10 000 years).

Secondly, the discount rate reduces the appraisal of future costs and benefits over time. A higher discount rate would result in a lower discounted stream of future benefits and a non-constant declining discount rate results in higher discounted stream of future benefits but as the investment costs exceed the benefits, this does not have a large effect on the overall outcome of the SCBA. In addition, investments concerning climate change adaptation are made for the long term (> 100 years), whereby uncertainties about climate change cannot be clearly expressed in cost-benefit analysis. Any cost or benefit occurring after 50 year, are difficult to quantify and use in the NPV calculation. Therefore it can be questioned whether decisions on climate change adaptation should solely be based on social cost-benefit analysis.

Table 4. Results of the social cost-benefit analysis of four adaptation options

	Adaptation option	Location	Net Present Value (million €; discount rate 2.5%)	Net Present Value (million €; discount rate 4%)
1.	Water storage in residential area	Zuidplas Noord	-20	-25
2.	Climate robust ecological network	Zuidplaspolder	50	34
3.	Climate robust design of a residential area	Nieuwerkerk Noord	27[a]	27[a]
4.	Climate proof construction of a residential area	Expansion Moordrecht Noord	-20[a]	-20[a]

[a] Net present value is the same for both discount rates because the high investment costs take place in period 1, while the low benefits (avoided damages) are spread over a period of 100 years.

5. Discussion and Conclusion

The climate is changing and important decisions related to spatial planning in the Netherlands need to take this into account. It is, however, impossible to assess these changes with complete certainty. By downscaling the IPCC climate scenarios to the Dutch KNMI climate scenarios, further down to the regional setting of the Zuidplaspolder a first step is made to identify the effects of climate change at a regional and local level and incorporate these effects in the future planning of this specific area. The spatial planning of the polder needs to take into account the increased risks of flooding caused by a dike breach along the Hollandsche IJssel and the effects of increased precipitation. The net present value of four adaptation options has been calculated, using a 2.5% discount rate and a time horizon of 100 years.

The systematic application of the assessment framework presented in this paper provided the inputs for an iterative planning process, where the active involvement of stakeholders has contributed to identification of costs and benefits of the adaptation options based on a detailed downscaling of the international climate scenarios to the local situation. The results of the cost-benefit analysis are an important starting point for further discussion and implementation of climate robust spatial planning. The results of the Zuidplaspolder case study have been discussed with the Dutch Ministry of Housing, Spatial Planning and the Environment and the

Province of Zuid-Holland to make the spatial planning of the Zuidplaspolder 'climate proof'. This resulted in additional financial resources to further climate proof the polder to ensure that the current and future inhabitants of the area are able to deal with the impacts of climate change. The strength of the approach is that it provides direct input for decision-makers responsible for spatial planning policies. The framework can also be applied to other low-lying coastal areas around the world that face the challenges of climate change.

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References

Adger, W.N. (2006). Vulnerability. Glob Environ Change 16, 268-281.

Adger, W.N., Arnell, N.W. and Tompkins, E.L. (2005). Successful adaptation to climate change across scales. Glob Environ Change Part A 15, 77-86.

Brander, L. (2008). Choice experiment Zuidplaspolder - Willingness to pay for landscape characteristics in the Zuidplaspolder. IVM-VU. Amsterdam

Bulkeley, H. (2006). A changing climate for spatial planning. Plan Theory Pract 7, 203-214.

Bürgenmeier, B., Baranzini, A., Ferrier, C., Germond-Duret, C., Ingold, K., Perret, S., Rafaj, P., Kypreos, S. and Wokaun, A. (2006). Economics of climate policy and collective decision making. Clim Change 79, 143-162.

CEPS (2008). ADAM Newsletter - Adaptation to climate change, why is it needed and how can it be implemented. Centre for European Policy Studies.

De Bruin, K., Dellink, R.B., Ruijs, A., Bolwidt, L., Van Buuren, A., Graveland, J., De Groot, R.S., Kuikman, P.J., Reinhard, S., Roetter, R.P., Tassone, V.C., Verhagen, A. and Van

Ierland, E.C. (2009). Adapting to climate change in The Netherlands: an inventory of climate adaptation options and ranking of alternatives. Clim Change *forthcoming*.

De Vries, J. (2006). Climate change and spatial planning below sea-level: Water, water and more water. Plan Theory Pract 7, 223-227.

Dixit, A.K. and Pindyck, R.S. (1993). Investment under uncertainty. Princeton University Press, New Jersey, USA.

Ebi, K.L. and Burton, I. (2008). Identifying practical adaptation options: an approach to address climate change-related health risks. Environ Sci Policy 11, 359-369.

ESPACE (2008). Climate change impacts and spatial planning decision support guidance. Environment Agency. Halcrow, UK

Fankhauser, S., Smith, J.B. and Tol, R.S.J. (1999). Weathering climate change: Some simple rules to guide adaptation decisions. Ecol Econ 30, 67-78.

Flood Protection Act (2006). Wet op de Waterkering. Staatsblad van het Koninkrijk der Nederland, No. 8, The Hague, the Netherlands

Goosen, H. (2006). Spatial water management. Supporting participatory planning and decision making. Techne Press, Amsterdam, the Netherlands.

Hof, A.F., den Elzen, M.G.J. and van Vuuren, D.P. (2008). Analysing the costs and benefits of climate policy: Value judgements and scientific uncertainties. Glob Environ Change 18, 412-424.

IPCC (2007). Summary for Policymakers. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press. Cambridge, UK

ISP (2006). Inter-municipality Development Plan Zuidplas (in Dutch: Intergemeentelijke Structuurplan Zuidplas). Projectbureau Driehoek RZG Zuidplas. The Hague, the Netherlands

ISV (2006). Inter-regional Development Vision (in Dutch: Interregionale Structuurvisie). Projectbureau Driehoek RZG Zuidplas. The Hague, the Netherlands

Klein, R.J.T., Nicholls, R.J. and Thomalla, F. (2003). Resilience to natural hazards: How useful is this concept? Glob Environ Change Part B 5, 35-45.

KNMI (2006). Climate in the 21st century, four scenarios for the Netherlands Royal Netherlands Meteorological Institute. De Bilt, the Netherlands

Leary, N.A. (1999). A framework for benefit-cost analysis of adaptation to climate change and climate variability. Mitig Adapt Strategies Glob Chang 4, 307-318.

Ministry of Finance (2007). Actualisatie discontovoet. Ministerie van Financiën, The Hague, The Netherlands.

Nota Ruimte (2006). National Spatial Strategy - creating space for development (in Dutch: Nota Ruimte: Ruimte voor Ontwikkeling). Ministeries van VROM, LNV, VenW and EZ. The Hague, the Netherlands

Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (2007). Climate change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press. Cambridge UK

Perman, R., Yue, M., McGilvray, J. and Common, M. (1999). Natural Resource and Environmental Economics. Pearson Education Limited, Essex, UK.

Pindyck, R.S. (2000). Irreversibilities and the timing of environmental policy. Resour Energy Econ 22, 233-259.

Pindyck, R.S. (2007). Uncertainty in Environmental Economics. Rev Environ Econ Policy 1, 45-65.

Rosenzweig, C., Major, D.C., Demong, K., Stanton, C., Horton, R. and Stults, M. (2007). Managing climate change risks in New York City's water system: Assessment and adaptation planning. Mitig Adapt Strategies Glob Chang 12, 1391-1409.

Rouwendal, J. and van der Straaten, J.W. (2007). Measuring welfare effects of spatial planning. Tijdschrift voor Economische en Sociale Geografie 98, 276-283.

Smit, B., Burton, I., Klein, R.J.T. and Street, R. (1999). The science of adaptation: a framework for assessment. Mitig Adapt Strategies Glob Chang 4, 199-213.

Smit, B., Burton, I., Klein, R.J.T. and Wandel, J. (2000). An anatomy of adaptation to climate change and variability. Clim Change 45, 223-251.

Smit, B. and Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. Glob Environ Change 16, 282-292.

Swart, R. and Raes, F. (2007). Making integration of adaptation and mitigation work: Mainstreaming into sustainable development policies? Clim Policy 7, 288-303.

Tol, R.S.J., Klein, R.J.T. and Nicholls, R.J. (2008). Towards successful adaptation to sea-level rise along Europe's coasts. J Coast Res 24, 432-442.

Tol, R.S.J. and Yohe, G.W. (2007). Infinite uncertainty, forgotten feedbacks, and cost-benefit analysis of climate policy. Clim Change 83, 429-442.

Van den Berg, J., Bessembinder, J., Idenburg, A., Stuyt, L.C.P.M. and Verbout, A. (2007). Climate sketch book for the Province of Zuid-Holland (in Dutch: Klimaatschetsboek Zuid-Holland). Amersfoort, the Netherlands

Van der Bolt, F.J.E. and Kok, M. (2000). Standardisation regional water systems. Modelling of damages. (In Dutch: Hoogwaternormering regionale watersystemen. Schademodellering). Rapport PR326, HKV/Alterra. Lelystad, the Netherlands

Wilson, E. (2006). Adapting to climate change at the local level: The spatial planning response. Local Environ 11, 609-625.

Xplorelab (2008). Final report Climate adaptation in the Zuidplaspolder (in Dutch: Eindrapport Klimaatadaptatie in de Zuidplaspolder). Hotspot Zuidplaspolder, Provincie Zuid-Holland. The Hague, the Netherlands

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[1] The figure shows the pilot projects for which the costs and benefits were identified in the ‘Hotspot Zuidplaspolder’ project

[2] The ‘Hotspot Zuidplaspolder’ project is part of the “Climate changes Spatial Planning” programme which aims to introduce “climate change and climate variability as one of the guiding principles for spatial planning in the Netherlands”. The project is financed by the CcSP programme and the Province of Zuid-Holland.