ECONADAPT

The Economics of Adaptation

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Deliverable 3.2: On the adaptation functions for macro adaptation modules of integrated assessment models

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Executive Summary

The literature on adaptation cost and effectiveness, albeit growing and supported by an increasing number of on-line data and case study collecting initiatives like e.g. the adaptation portal and Climate Adapt (the EU adaptation portal maintained by the European Environment Agency), is still sparse. The biggest challenge with adaptation relates to its highly site/case-specific nature, which makes it very difficult to produce meaningful aggregated measures on either adaptation costs or effectiveness using uncontroversial aggregation criteria.

However, some aggregation of adaptation costs and effectiveness is necessary when this "family" of measures has to be evaluated in a more strategic perspective, for instance comparing its relative convenience and viability against other actions to cope with climate change (e.g. mitigation), or, more in general, against other alternative uses of public and private funds.

Aggregation is then unavoidable, when the assessment of adaptation policies is conducted with a macroeconomic perspective which is typical in climate change impact and policy integrated assessment exercises.

This deliverable initially revises the existing literature on cost and benefit of adaptation to verify if the information available would allow building adaptation functions into the CGE model used within the ECONADAPT project. Results of this scrutiny show that, at best, cost-effectiveness ratios for adaptation in different areas, and in just a subset of countries, can be determined. This information is however highly insufficient to allow the implementation of adaptation functions into a CGE model. Accordingly, the calibration of adaptation in the ICES model will be based on a completely different approach; rather than trying a highly controversial if not unappropriated extrapolation and generalization from the literature.

However, to enrich this deliverable, section 3 suggests an in-depth methodology to model adaptation against sea-level rise, while section 4 describes the methodology applied to implement adaptation in to dynamic optimization models.

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1 Introduction

The literature on adaptation cost and effectiveness, albeit growing and supported by an increasing number of on-line data and case study collecting initiatives like e.g. the adaptation portal and Climate Adapt[1] (the EU adaptation portal maintained by the European Environment Agency), is still sparse. The biggest challenge with adaptation relates to its highly site/case-specific nature, which makes it very difficult to produce meaningful aggregated measures on either adaptation costs or effectiveness using uncontroversial aggregation criteria.

However, some aggregation of adaptation costs and effectiveness is necessary when this “family” of measures has to be evaluated in a more strategic perspective, for instance comparing its relative convenience and viability against other actions to cope with climate change (e.g. mitigation), or, more in general, against other alternative uses of public and private funds.

Aggregation is then unavoidable, when the assessment of adaptation policies is conducted with a macroeconomic perspective which is typical in climate change impact and policy integrated assessment exercises.

Independently upon the theoretical underpinnings of the different approaches, and of the representation of the economic system used (be it by dynamic optimization growth models, Computable General Equilibrium (CGE) models or, even though less frequently, macro-econometric models) they are all characterized by a “spatially” aggregated representation of the economy, where the finest investigation unit is the country.[2] This alone requires the consideration of adaptation as a nation-wide strategy, grouping somehow expenditures and effectiveness of different adaptation measures at the country level. At best, adaptation can be differentiated according to the different domain in which it operates e.g. coastal protection, health protection etc.

This evidently poses non negligible challenges to the calibration of adaptation cost and effectiveness functions in integrated assessment models. The approach followed in this work is thus the following. Initially we revised the existing literature and verified the amount of information available. Results of this scrutiny are extensively reported in appendix 1 and briefly commented in section 2. We verified that, at best, cost-effectiveness ratios for adaptation in different domains can be determined. This information is however highly insufficient to allow the implementation of adaptation function into a CGE model like ICES that is the tool that the ECONADAPT project is using in the subsequent D8.2 for the analysis of planned adaptation. Accordingly, the calibration of adaptation in the ICES model in D8.2 will be based on a completely different approach: rather than trying highly controversial if not unappropriated extrapolation and generalization from the literature, specific data for adaptation against sea-level rise, for irrigation, and protection against river floods, are derived from engineering/bottom-up impact models. This process is extensively described in D8.2.

However, to enrich this deliverable, section 3 suggests an in-depth methodology to model adaptation against sea-level rise, while section 4 describes the methodology applied to implement adaptation in to dynamic optimization models, which is however incompatible with the structure of a CGE model like ICES. Section five concludes.

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[1] http://climate-adapt.eea.europa.eu/

[2] In dynamic optimization models also the sectoral representation of the economy is coarse featuring one production sector.

2 Cost-Benefit ratios of adaptation measures from the literature

This section presents an overview of 47 studies selected from a larger set from the existing literature[3] for which it was possible to identify directly or indirectly, using additional information provided from the studies themselves, a cost effectiveness (CE) ratio of adaptation. The studies tackle adaptation in different impact areas (the number of studies in parentheses): water (6), infrastructure (2), health (6), ecosystem (5), energy (3), and agriculture (25). All the information summarised in Table 1 has been organised in tables dedicated to each category reported in appendix A. An accompanying Excel file reports more detailed information for each specific adaptation measure along with the costs and benefits data used to estimate the CE ratios (file: Deliverable 3.2-CostBenefit Ratios.xlsx).

Table 1: Cost-Benefit ratios for adaptation measures to cover water availability

	Studies	Impacts	Number of Adaptation measures	Geographic coverage
Water	6		6	Kenya, Greece, Nepal, OECD, Gambia, Malawi
Infrastructure	2	Heat, Precipitation, Multiple Risk	4	Germany, EU27
Health	6	Heatwaves, Food, water borne and vector borne diseases	4	Flanders, Rome, Kenya, France, China, Global
Ecosystems	5	Sea-level rise, extreme weather events, flooding, loss of coastal habitats, increased flood risk	23	Belgium, Netherlands, UK, Samoa
Energy	3	Global warming	2	Netherlands, Tanzania, Kenya
Agriculture	25	Soil degradation, water shortage, Cross cutting impacts	27	local, Germany, UK, Netherlands, Portugal, USA, Austria, Finland, France, Greece, Italy, Spain, Sweden, EU15, EU
Total	47		66	

The country and impact coverage from the different studies is not uniform. Most data refer to EU countries or the EU as a whole. The rest of the world is scarcely represented. The bulk of studies address adaptation in agriculture; water and health follow. On their turn, a wide variety of adaptation measures is considered depending on the sectors and the corresponding impacts. Unfortunately the single studies do not allow us to characterize adaptation costs and effectiveness as required by a global CGE model like ICES. It could, however, allow the calibration of adaptation functions in more aggregated models like some dynamic optimization models. This possibility will be discussed in section 4.

[3] This consists of the information collected for *Deliverable 3.1A: Using cost and benefits to assess adaptation option*s.

3 Adaptation to sea level rise

3.1. A general framework for SLR economics

The economic analysis of sea level rise follows a four step procedure. The ***first step*** (estimate extent of physical damage) covers the means by which physical damages are identified and quantified. These damages could include metrics such as hectares of lost land, extent of property damage and numbers of people displaced. To arrive at these estimates, it is necessary to synthesise a large amount of 'upstream' data including: greenhouse gas (GHG) emissions, their impact on temperature, the consequent impact on sea level and local coastline characteristics.

The ***second step*** (estimate extent of economic damage) covers the means by which the identified physical damages are converted into economic damages. This includes attaching a monetary value to the losses identified (e.g. property values, removal costs) and may also go further to include estimates of the lost economic output and/or human welfare change attributable to SLR.

The ***third step*** involves identifying available adaptation responses which, in the event of the projected SLR, will reduce the extent of the damage (to below the level estimated in steps one and two).

Finally, the ***fourth step*** examines the economics of adaptation which involves comparing the costs of the identified responses with the benefits (i.e. avoided damages). This step may also involve the use of optimisation techniques to determine the optimal timing, location and extent of adaptation interventions.

In the next subsections, we examine a set of papers in light of the steps identified above. While this list is by no means exhaustive, the studies provide variety in their geographical resolution and illustrate how the techniques of SLR economics have evolved over time.

- Fankhauser (1995) starts from first principles and derives a theoretical framework for the economics of SLR. It is of particular interest, since it constructs a coherent applied optimisation framework without the support of the powerful models and databases used in later studies;

- Tol (2007) provides a global estimate of SLR damages and adaptation costs using the FUND model;

- Hinkel et al. (2014) provides global estimates of SLR damages and adaptation costs using the DIVA model, as part of the ISI-MIP project;

- Neumann et al. (2014) estimates damages and adaptation costs at national level (USA). The paper is also notable since it explores the potential damages due to changes in storm surge patterns, as well as SLR itself;

- Hallegatte et al. (2011) estimates damages and adaptation potential at city level (Copenhagen) and is noteworthy since it also estimates the indirect economic costs of a flooding event;

- Yohe et al. (2011) features an economic framework which illustrates the importance of risk preferences and uncertainty as perceived by economic agents and the insurance industry. It also features an applied case study for Boston, USA (based on Kirschen et al., 2008).

For the remainder of this section, papers will be referred to by the name of the lead author (e.g. *Tol*).

3.2. Estimating the extent of physical damage

The methods for dealing with physical damages in each paper are summarised in Table 2.

SLR and storm surge estimates

In this literature, damages from SLR consist of permanent inundation and/or damage due to storm surges. Fankhauser and Tol consider permanent inundation only. The other studies also consider storm surges in terms of the increased "launch height" created by SLR. Neumann also includes two case studies (Tampa and New York) where a cyclone simulation model is used to estimate changes in storminess attributable to climate change. All other studies assume that storm patterns remain unchanged, due to lack of data.

In terms of sea level itself, two studies (Fankhauser and Yohe/Kirshen) assume discrete changes by 2100 on a *what if?* basis (ranging from 0.2m to 2m by 2100). Hallegatte chooses the range of global SLR projections from the IPCC Fourth Assessment Report (AR4) and adjusts them to obtain a plausible range for Northern Europe. The other studies use SLR projections that are consistent with specific climate scenarios (SRES, RCP or IGSM-CAM).

Types of damage considered

In all studies, the damages from SLR are considered to consist of property damaged or destroyed, though Tol and Hinkel also explicitly consider the number of people displaced. In this section of the note we consider how the extent of the physical damage is quantified, leaving discussion of economic valuation methods for the next section.

In Fankhauser and Tol, the area of land lost (in the absence of protection) is assumed to increase linearly in SLR. In Fankhauser, the dryland loss parameter (ψ) represents the land area lost per cm of SLR and km of undefended coastline. Wetland loss is also represented by ψ, though this is partially offset by gains due to the inland migration of wetland along the portion of coastline that is undefended (α). Tol performs a similar operation, deriving area-at-risk estimates from population density data. In all other studies this sort of relationship is replaced with a spatially explicit framework that uses elevation models and a variety of property and population datasets to capture the distribution of property and people at different elevations along the floodplain.

Increased exposure over time

With the exception of Hallegatte, all studies consider exposure (regardless of SLR) to increase over the course the 21st century due to increases in wealth and population. Hinkel and Tol project population in the coastal areas to increase in line with SSP and SRES scenarios respectively, while Yohe/Kirshen make explicit estimates of the rate at which population will increase in different areas of the Boston floodplain. The other studies base changes in exposure on growth in GDP and/or asset values, which are discussed in the next section.

Table 2: Methods for Estimating Physical Damages from SLR

Paper (region coverage)	**Physical Damage Metrics**	**SLR projection**	**Geographic / Topographic Data**	**Human Geography Data**
Fankhauser (OECD)	Inundated area	0.2 – 2 m by 2100	IPCC (1990)	IPCC (1990)
Tol (global)	Inundated area & number of people displaced	SRES scenarios from IMAGE model	Hoozemans *et al.*(1993)	Hoozemans *et al.*(1993) Bijlsma *et al.* (1996)
Hinkel (global)	Number of people exposed	4 RCP scenarios with 4 General Circulation Models (GCMs)	SLR Refs 15-18 of Hinkel *et al.* (2014) Topography Digital Elevation Models GLOBE and SRTM	Population density from GRUMP and LandScan datasets
Neumann (USA)	Property damage	SLR One climate scenario with 3 GCMs Storm Surge Florida and New York case studies	SLR IGSM-CAM scenario and GCMs detailed in Monier *et al.* (2014) Storm Surge methods from Neumann *et al.* (2012) and Emanuel *et al.* (2008).	NCPM model of US-EPA incorporates elevation, subsidence and property value at 150 × 150 m grid level. (Neumann *et al.*, 2011)
Hallegatte (Copenhagen, Denmark)	Insured value of assets (residential, commercial & industrial) + Estimated value of infrastructure	SLR range from AR4, including expected deviation of Northern Europe from global mean	Topographic data from SRTM Digital Terrain Model	Asset exposure from RMS Winterstorm model (proprietary data)
Yohe & Kirshen (Boston, USA)	Property damage	0.6m & 1.0m SLR by 2100 (with Monte Carlo analysis to produce a range of outcomes around each SLR estimate)	Floodplain areas and water levels from Federal Emergency Management Agency & US Army (Weiner, 1993)	Residential, commercial & industrial areas at risk taken from MassGIS information system

3.3 Estimating economic damages

Each paper's method for dealing with economic damages is summarised in Table 3.

Types of economic damage considered

In each case, the economic impact is considered to consist primarily of damage to property. The damage consists of an assumed, or modelled, relationship between the value of assets and the fraction of that value 'consumed' by repair or damage costs in historical flood events. For example, Hallegatte uses *vulnerability curves* provided by the company RMS, while Hinkel assumes an asset:GDP ratio of 2.8 and then imposes a logistic relationship between damage costs and depth of inundation. Fankhauser takes a slightly different approach by classifying damages as the income foregone from the inundation of a hectare of land. This is represented by the land value multiplied by the cost of capital. In all cases except Hallegatte (where the economic element is comparative static) the increase in asset exposure over time is estimated using GDP and population projections. Tol also explicitly considers the cost of displaced people, valuing forced migration at three times GDP per capita.

Indirect damages (Hallegatte)

Hallegatte considers both direct and indirect damages. Direct damages are defined as repair and replacement costs. Indirect costs are considered to be the lost production of goods and services created by the disaster. Hallegatte states that these costs are equal by definition to the lost consumption of goods and services caused by the inundation (on the basis that all damages are eventually repaired and consumers sacrifice consumption to enable repairs in the meantime). Indirect effects are estimated using the ARIO input-output model. This estimates the reduction in the economy's capacity created by the flooding, and then models the changes in sectoral value-added (VA) and employment over time as activity shifts to the construction and manufacturing sectors in order to restore overall capacity to its former level.

The study finds that indirect losses are smaller than direct losses but are also highly nonlinear in SLR. For example, total losses are estimated to be €1.68 billion for a 1 metre SLR event (of which under 1% are indirect losses) and €10 billion for a 3 metre event (of which 7.5% are indirect).

Loss values and risk aversion (Yohe)

Yohe/Kirshen's value damage costs in a similar way to the other studies (as the expected actual costs incurred under future SLR conditions). However, Yohe also demonstrates that agents value the potential losses more highly than this if they are risk averse (which is usually assumed in the finance industry). Therefore their willingness to pay for insurance will be greater than the estimated damage cost. The authors argue that this willingness to pay also represents the value of adaptation. Therefore damage cost estimates (such as those presented in the other studies) can only be considered a fair valuation of SLR losses if one or both of following conditions are met:

i) **agents are risk neutral** - so their subjective valuation of losses is the same as the probabilistic best estimate; or

ii) **insurance markets are actuarially fair:** so that insurance is available and premiums are based on the probabilistic loss estimate (*i.e.* as if agents were risk neutral)[4].

In a 'second best' world where neither of these conditions hold (which the authors consider to be a realistic description of reality) the value of avoiding losses is greater than the damage cost estimate. This concept is discussed in greater detail in the *economics of adaptation* section below.

[4] An actuarially fair insurance market is roughly equivalent to a perfectly competitive goods market, where the industry's expected profit is zero. As risk is shared widely across the population, the industry's expected income from premiums is equal to its expected payouts to 'unfortunate' customers. Moreover the price of insurance is equal to probability of disaster π. This means that consumers will only pay the 'probabilistically fair' price π for insurance (even though they are willing to pay more because they are risk averse). As a result, the actuarially fair insurance market is equivalent to a situation where agents are risk neutral — and probability-based damage estimates represents a fair valuation in both cases. This is demonstrated algebraically in Yohe.

Table 3: Methods for Estimating Economic Damages from SLR

Paper **(region coverage)**	**Economic Damage Metrics**	**Method of Evaluating Economic Damages** **(without adaptation)**	**Data Sources**
Fankhauser (OECD)	Annual income flow from land, foregone due to inundation.	Income = annual land value × rate of return on capital Annual land value = initial land value, increasing annually at rate of economic growth.	Author estimates based on literature
Tol (global)	Monetary value of land lost & valuation of displacement of people	Value of land assumed to be proportional to GDP per km^2. Displacement valued at 3 × GDP per capita	Author estimates based on literature
Hinkel (global)	Monetary value of damage to assets	Value of exposed assets related to population and GDP (with assumed asset: GDP ratio). Depth-damage function assumes marginal damage declines as submergence increases.	Vafeidis *et al.* (2008) Hallegatte *et al.* (2013) Messner *et al.* (2007)
Neumann (USA)	Property damage	Property value data and economic impact estimate included in NCPM model, featuring population and GDP projections from CIRA project.	Neumann *et al.* (2011)
Hallegatte (Copenhagen, Denmark)	Direct damages Repair and replacement costs of assets	Vulnerability curves estimate damages as function of insured asset values. Damages to infrastructure (uninsured) based on Louisiana following Hurricane Katrina.	Asset values and vulnerability curves from RMS data. Louisiana Recovery Authority.
	Indirect damages Reduced production possibility during reconstruction period	Regional input-output model (ARIO) captures value-added and employment effects during reconstruction period (assumes all damage repaired)	Hallegatte (2008) and Denmark national statistics
Yohe & Kirshen (Boston, USA)	Residential, commercial and industrial property damage	Residential Estimated damages to property based on data from US Census and FEMA Industrial & Commercial Damage cost per hectare based on US Army Corps of Engineers study	United States Census Bureau (2000) FEMA (1999) US Army Corps of Engineers (1990)

3.4. Identifying Adaptation Options

Sea walls and alternative strategies

Table 4 lists the adaptation options considered in each paper. The predominant adaptation option is a sea wall. This is understandable from an analytical perspective since the costs and benefits of this type of 'hard' adaptation measure are conceptually easy to quantify. It is straightforward to define the benefits of a sea wall as the absence of inundation (provided the wall is sufficiently high), while there may not be a robust basis for estimating the costs and effectiveness of alternative measures (such as education or an early warning system). Neumann also considers beach nourishment, since both options are available in the NCPM model. Yohe considers sea walls for urban areas and a floodproofing scenario for suburbs. New sea walls capable of withstanding a current 500-year event are assumed to cost $7,200 per linear metre. The cost of floodproofing (of the buildings themselves rather than the entire land area) is assumed to be $3,500-17,000[5] per home (or 10% of avoided damage costs for commercial and industrial buildings).

Sources of protection cost data

It is notable that Hinkel and Hallegatte each derive the costs of a sea wall from the same source as Tol; the 1993 Global Vulnerability Assessment of Hoozemans *et al*. These estimates assume, for the sake of simplicity, that defence costs are linear in wall height. Yohe also uses a single cost figure per metre of defence, without adjusting wall height to expected SLR. When compared to the earlier studies of Fankhauser and Tol, these studies are considerably more advanced in their estimates of exposure to SLR (use of property value databases and topographic models). It is therefore surprising, that the same improvement in data cannot be seen in the calculation of protection costs.

On this basis it appears that a review of the state of the art in cost estimates for sea walls (and other adaptation options) would be an important addition to any cost benefit assessment of SLR impacts and adaptation.

Table 4: Adaptation options considered in each paper

Paper (region coverage)	**Type of adaptation**	**Data Sources**
Fankhauser (OECD)	Sea wall Protection cost increases exponentially with wall height. Wall can be built gradually as sea level rises.	Construction costs from IPCC (1990)
Tol (global)	Sea wall	Hoozemans *et al.*(1993)
Hinkel (global)	Sea wall	Mainly Hoozemans *et al.*(1993)
Neumann (USA)	Sea wall & beach nourishment	NCPM model of US-EPA
Hallegatte (Copenhagen, Denmark)	Sea wall	Hoozemans *et al.*(1993)
Yohe & Kirshen (Boston, USA)	'GREEN' defences for suburbs (floodproofing of buildings in the 500 year floodplain) Sea walls ('Build Your Way Out') for urban areas	FEMA (1999) US Army Corps of Engineers (2000)

[5] The low and high figures represent homes in the current 100 year and 500 year floodplain respectively

3.5. Economics of Adaptation

In this section, we examine the ways in which each paper provides insight into the costs and benefits of adapting to SLR by combining the damage estimates from Step 2 with the adaptation measures identified in Step 3. This information is summarised in Table 5.

Calculating the optimal degree of adaptation (Fankhauser, Tol, Hinkel, Neumann)

Three papers (Fankhauser, Tol and Hinkel) use an optimisation framework in which the optimal degree of adaptation is calculated as a first order condition at the point where the marginal costs and benefits of adaptation are equalised. For Fankhauser and Tol, the variable to be optimised is *L* the proportion of coastline to be protected. For Hinkel, the variable to be optimised is *F* the design return period[6] of coastal defences (Equation 1).

Equation 1: First order protection condition (Hinkel)

$$F^* = y^{\frac{\lambda-\mu}{\phi-\theta}} P^{\frac{\epsilon}{\phi-\theta}} (1+S)^{\frac{\chi-\gamma}{\phi-\theta}} \left(\frac{\alpha\theta}{\beta H_{100}\phi}\right)^{\frac{1}{\phi-\theta}}.$$

Here, the optimal design return period F^* is assumed to increase with population density (*P*) and scaled GDP per capita (*y*), and fall as the extreme 100 year water level (H_{100}) rises. The Greek letters are parameters derived from the literature (mostly Hoozemans *et al.*, 1993). This procedure is carried out for each of the 12,148 segments of the (global) coastline featured in the DIVA model (Hinkel & Klein, 2009).

Fankhauser and Tol employ a similar first order condition (shown below) in which the optimal degree of protection (L^{opt}) has a positive relationship with the net present value (NPV) of future dryland losses (*DL*), and a negative relationship with the cost of protection (*PC*) and gains in wetlands[7] (*WG*).

Equation 2: First order protection condition (Fankhauser)

$$L^{opt} = 1 - \frac{1}{2}\left(\frac{PC^{pv} + WG^{pv}}{DL^{pv}}\right)$$

Fankhauser concludes that for SLR estimates of between 20 and 200 cm affecting OECD countries by 2100, it is optimal to protect almost all cities and harbours (over 95% by coast length), around 80% of open coasts, and 50-60% of beaches. Tol considers a scenario of 66 cm SLR by 2100 and concludes that a high degree of protection (almost 100%) is chosen by all

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[6] A design return period T means that the sea wall should not be breached by a sea level rise event occurring every T years on average.

[7] Creation of new wetlands (migration) is a natural response to SLR, that is prevented by construction of sea walls. Therefore reduced migration is considered a cost (*i.e.* negative benefit) of sea wall construction.

countries who would otherwise lose land. The least protected countries are Kiribati (74% of vulnerable coastline protected) and New Caledonia (94%).

Hinkel does not report how much protection is optimal (though this is part of the paper's calculations, as Equation 1 shows). Therefore, we do not know how much land is optimally left unprotected. However, the study estimates that with additional sea wall construction damage costs would be 2-3 orders of magnitude lower than damages with only 1995 levels of protection (up to 9.3% of global GDP (RCP8.5 scenario)).

In Neumann, adaptation decisions are made by the NCPM model on a per-grid-square basis. In each square, adaptation (beach nourishment or sea wall construction) is undertaken if its NPV[8] is positive. In this way Neumann counts the optimal number of grid squares to protect, rather than calculating the optimal share of a (larger) coastline. Like Hinkel, Neumann reports results as total costs (adaptation + residual damages). In the absence of mitigation, total costs are $419-536 billion, of which 50-55% consists of sea wall construction, 30-35% consists of beach nourishment, with abandonment (residual damages) accounting for the rest.

Presenting the value of adaptation investments (Yohe)

Yohe goes further than the other studies by investigating the effect of risk preferences on adaptation investments. Assuming that agents are risk averse, the study considers two policy interventions i) provide actuarially fair insurance to all[9]; and ii) invest in protection (sea walls and floodproofing for urban and suburban areas respectively). The annual net value of the floodproofing investment for a 1m SLR scenario, and for different values for the coefficient of relative risk aversion (RRA), is shown in Figure 1. This shows that the value of floodproofing is higher for greater values of RRA and increases over time. Yohe's review of the literature suggests that the correct value for RRA is between 0 and 3 (with a mean value of 1.49). Since the availability of actuarially fair insurance is equivalent to reducing RRA to zero (risk neutrality), it also has the effect of reducing the net value of the adaptation option.

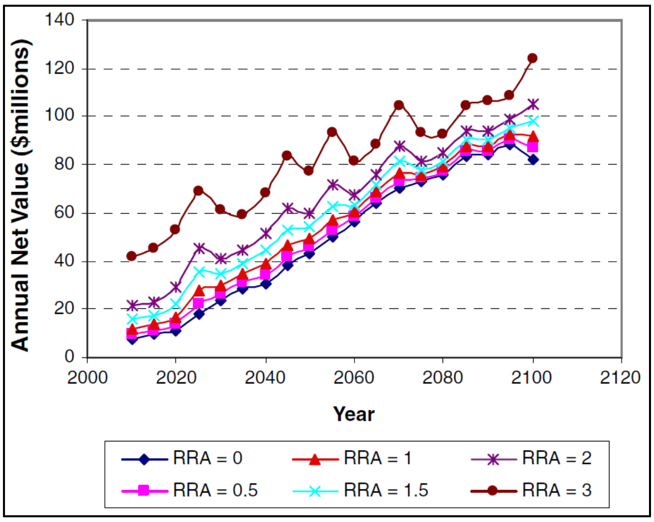

Figure 1: Annual net value of floodproofing adaptation under different relative risk aversion (RRA) (Yohe *et al.* 2011)

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[8] Present value of benefits minus present value of costs.

[9] Note that imposing an actuarially-fair insurance market is equivalent to imposing risk neutral preferences, as discussed in Step 2.

Yohe's findings show that in a 'second best' world, where agents are risk averse and actuarially fair insurance is unavailable, the value of adaptation is higher. Therefore, when agents are risk averse, estimates that fail to take account of the availability of insurance could be considered underestimates.

Furthermore, Yohe's findings show that insurance is, to some extent, a substitute for adaptation investments. In Figure 1, the net value of floodproofing is positive in all time periods, even when insurance is available, meaning that floodproofing is worthwhile. However, in other cases where benefits are smaller (or costs are greater) it is possible that adaptation investment becomes worthwhile only once a lack of adequate insurance is taken into account. Furthermore, in a world where capital is constrained, a positive net value may not be a sufficient criterion to justify investment. For example, the adaptation project's rate of return may have to exceed the rate at which the government (or a private investor) is able to borrow funds. Alternatively, scarce capital may need to be allocated among competing projects on the basis of expected return. In these cases the availability of insurance could have an important role in replacing or delaying expenditure on marginal adaptation projects.

Presenting adaptation needs (Hallegatte)

Hallegatte does not explicitly calculate the value of adaptation. However the study still makes a case for the viability of sea walls by comparing the mean annual losses from flooding to the sea wall construction cost of "a few hundred million Euros" for the city of Copenhagen. The paper's relationship between mean annual damages (direct and indirect) and protection levels is shown in Figure 2, which shows that for any given protection level, losses increase nonlinearly as sea level rises. For example, annual losses at 75 cm SLR are around €100 million for a defence of 250 cm. However, as Figure 2 shows, losses at 100 cm and 125 cm SLR are greater by orders of magnitude greater for the same 250 cm level of defence. Construction of a 300 cm sea wall therefore appears sensible when SLR is expected if protection costs are a few hundred million Euros and increase linearly in wall height (as Hallegatte states).

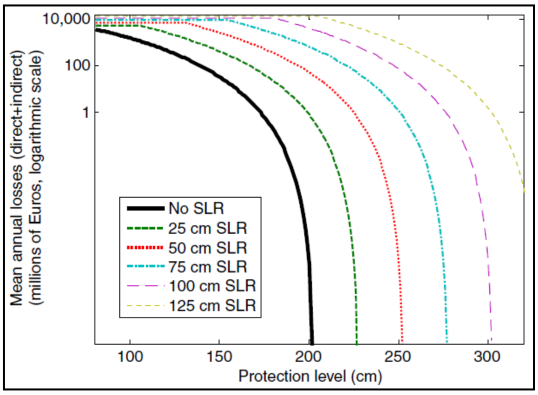


Figure 2: relationship between mean protection level and annual loss from coastal flooding (Hallegatte *et al,* 2011)

Table 5: Methods for appraising the economics of adaptation to SLR

Paper (region coverage)	Basis for Economic Assessment of Adaptation
Fankhauser (OECD)	Cost-benefit optimisation Solve for L* - the optimal proportion of coastline to protect
Tol (global)	Cost-benefit optimisation Solve for L* - the optimal proportion of coastline to protect
Hinkel (global)	Cost-benefit optimisation Solve for F* - the optimal degree of protection
Neumann (USA)	Sea wall, or beach nourishment chosen (per grid square) if NPV(benefit)>NPV(cost). Otherwise abandonment.
Hallegatte (Copenhagen, Denmark)	Mean annual losses calculated for different combinations of SLR and sea wall height. No explicit optimisation.
Yohe & Kirshen (Boston, USA)	Study calculates Net Present Value (NPV) of adaptation options & examines how NPV is affected by risk attitudes and insurance markets

3.6. Discussion

Each of the papers examined in this section demonstrates the importance of adapting to SLR. They do this either by using an explicit optimisation framework to demonstrate that the majority of coastline should be defended, or by demonstrating that potential damage costs should exceed the costs of protection in most circumstances considered. It is difficult to compare the results of the papers in greater detail, since they deal with different SLR scenarios and different spatial scopes. However, after comparing the techniques employed in each paper, the following observations emerge, that should be considered in future economic analysis of SLR.

Quality and detail of data has improved

Comparison of recent studies against the older analysis of Fankhauser and Tol shows that considerable progress has been made in quantifying economic exposure to SLR. Per-country estimates have been replaced with detailed models and databases of coastal topography, and the distribution of people and assets. The (local level) data on exposed asset values of Hallegatte and Yohe/Kirshen are particularly detailed. However, every paper features some calculations that are based on heuristics with limited empirical support. For example, Hinkel uses a single asset:GDP ratio to convert spatial population data into estimates of exposed assets, and most studies use some sort of heuristic to derive damage estimates from exposed asset values.

All papers have some (noted) limitations

Notable limitations acknowledged in each paper include the need to consider the effect of climate change on storminess, and the need to consider a wider range of adaptation options than the hypothetical sea wall (and floodproofing) considered in most cases. Some authors also note that the comparison between 'with adaptation' and 'no adaptation' cases is merely illustrative and is unrealistic as a 'true' damage estimate (since autonomous adaptation, or even maladaptation is likely to occur once emerging SLR risks become apparent).

The state of the art appears to be more advanced in impacts than adaptation

In terms of costing the adaptation options identified, three studies rely on cost data from Hoozemans *et al.* (1993). With the exception of Neumann, all studies use cost data from 2000 or earlier, while some do not adjust wall height to take account of different SLR scenarios, or assume that wall costs are linear in SLR. The validity of these assumptions appears to be largely untested and may therefore be an important area for investigation.

Are expected damage and repair costs to property the appropriate loss metric?

In most papers, the losses from SLR consist of repair costs and the value of assets abandoned. Fankhauser instead considers losses to be the lost income stream from land that is permanently inundated (and includes a 'merit order' framework whereby inundation increases the value of the non-inundated land). Hallegatte also considers indirect losses, which though small (under 10% of total loss over the range considered) increase rapidly as sea level rises. Yohe also considers the effect of risk preferences, arguing that the value of a possible loss is greater than the 'certainty equivalent' value of the damage, once agents' likely risk aversion is taken into account.

'Marginal' decision makers need better information in neglected areas

This review has shown that in many cases, the benefits of adaptation exceed the cost by several orders of magnitude. However when investment decisions are marginal, neglected factors become more important (such as the state of the insurance market and the quality of protection cost data). This is particularly true when adaptation funds are scarce or the optimal timing of the investment is debatable. Therefore, it is reasonable that scientific improvements up to now have concentrated on the largest cost item (exposure), particularly when analysing SLR over the long-term and at low spatial resolution. However if the goal of future analysis is to move to a more 'marginal' intervention space (*i.e.* closer in time and higher geographical resolution), greater attention should be paid to adaptation costs and the role of risk and insurance.

Using the in-depth review method we were mainly able to construct heuristics from the 2007 paper of Tol, as well as collecting isolated pieces of information from other studies. For example, Hallegatte and Kirshen cite other studies in claiming that the costs of a sea wall are around $2.5 million and $1-7.2 million respectively. The most interesting heuristic resulting from this exercise is the optimal protection period calculation derived from Hinkel. However, this is only a formula (for which we had to estimate some parameters). Additional data and quality control would therefore be required in order to deploy this formula in JRC-ECONADAPT analysis.

Using the ECONADAPT database method, we reviewed 22 studies, of which four were also part of the detailed review process (rather than an ECONADAPT selection). Seven studies were found not to contain useable data. The other studies offered a variety of data points that varied across location, spatial scope, climate scenario and concept (value of wetland, cost of building sea defence…). Compared to the in-depth review process, this data lacks uniformity, which makes it more challenging to consider how it could be used for to develop heuristics and transfer rules.

4 Including adaptation in a dynamic optimization integrated assessment model. An alternative approach.

This section presents an alternative approach to include aggregated information on the costs and benefits of adaptation in a macroeconomic model used for the integrated assessment of adaptation AD-WITCH (Bosello et al. 2010, 2013, Bosello, F., and E. De Cian 2014).

AD-WITCH is an intertemporal, optimal growth model in which forward-looking agents choose the path of investments to maximise a social welfare function subject to a budget constraint. A reduced-form global circulation model links emissions from industrial activities to temperature increase. In turn the temperature increase translates into GDP losses via a reduced-form climate change damage function (Figure 3 left). The model depicts 12 world macro-regions[10] and simulates until 2100. It uses a disaggregated representation of the energy system detailed into many energy production technologies.

To represent endogenous optimisation decisions to adapt, in AD-WITCH, adaptation has to be modelled as an additional set of control variables that concur with all the other controls, namely investments in physical capital, R&D, and energy technologies, to maximize regional utility. AD-WITCH is an aggregated model either regionally or sectorally. Accordingly, also the representation of adaptation decision has to be modelled with a similar "resolution". To do so, the large number of possible adaptive responses has been aggregated into four macro categories: generic and specific adaptive capacity-building, anticipatory and reactive adaptation, organized by a nested sequence of CES functions (Figure 3 **The AD-WITCH model** right).

[10] These are: USA (United States), WEURO (Western Europe), EEURO (Eastern Europe), KOSAU (Korea, South Africa, Australia), CAJANZ (Canada, Japan, New Zealand), TE (Transition Economies), MENA (Middle East and North Africa), SSA (Sub-Saharan Africa), SASIA (South Asia), CHINA (China and Taiwan), EASIA (South East Asia), LACA (Latin America, Mexico and Caribbean). Focus of BASE is the EU. In AD-WITCH WEURO includes: Andorra, Austria, Belgium, Denmark, Faroe Islands, Finland, France, Germany, Gibraltar, Greece, Greenland, Iceland, Ireland, Italy, Liechtenstein, Luxembourg, Monaco, Netherlands, Norway, Portugal, San Marino, Spain, Sweden, Switzerland, United Kingdom. EEURO includes: Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia

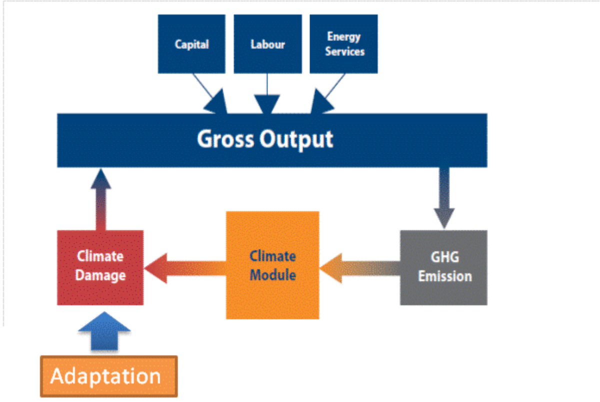
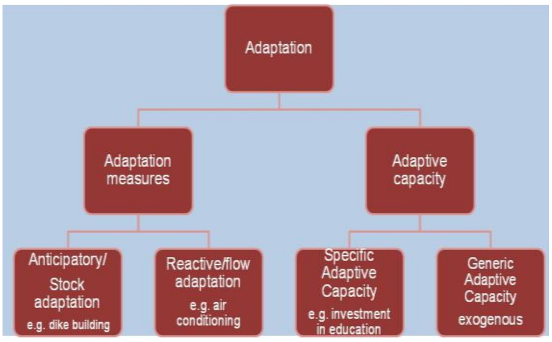
Structure of the AD WITCH model	Adaptation “tree” in the AD-WITCH model
	

Figure 3 The AD-WITCH model

Generic adaptive capacity building captures the link between the status of the development of a region and the final impact of climate change on its economic system. Specific adaptive capacity building accounts for all investments dedicated to facilitate adaptation activities (e.g. improvement of meteorological services, of early warning systems, the development of climate modelling and impact assessment etc.). Anticipatory adaptation gathers all the measures where a stock of defensive capital must already be operational when the damage materialises (e.g. dike building). By contrast, reactive adaptation gathers all actions that are put in place when the climatic impact effectively materialises (e.g. use of air conditioning) to accommodate the damages not avoided by anticipatory adaptation or mitigation.

Table 6 reports the adaptation measures considered in the AD-WITCH model. It also reports the reference literature on cost and effectiveness of adaptation which allowed the calibration of the respective adaptation functions. The calibration procedure, similarly to what discussed in section 2, consisted in identifying costs and benefits of the different adaptation types, for each of the WITCH regions. The calibration point is represented by a doubling of CO_2 concentration.

Table 7 reports the present estimates of adaptation cost and effectiveness used in AD-WITCH at the calibration point, while Figure 4 depicts the respective adaptation cost effectiveness curves.

Table 6. Adaptation activities whose cost and effectiveness allowed the calibration of adaptation functions in AD-WITCH

Proactive adaptation measures → Modelled as "stock" variable*
✓ Coastal Protection Activities. **Costs:** DIVA model **Effectiveness:** DIVA model ✓ Settlements, Other Infrastructures (Excluding Water) and Ecosystem Protection Activities **Costs:** Nordhaus and Boyer (2000), **Effectiveness:** Nordhaus and Boyer (2000) ✓ Irrigation **Costs**, Kirshen (2007) **Effectiveness** Tan and Shibasaky (2003), Parry et al (2009)
Reactive adaptation measures → Modelled as "flow" variable*
✓ Agricultural Adaptation Practices. **Costs:** Tan and Shibasaky (2003), Parry et al. (2009) **Effectiveness:** Tan and Shibasaki (2003),EEA (2007), Kirshen et al. (2006) ✓ Treatment of Climate-Related Diseases **Costs**, Tol and Dowlatabady (2001) **Effectiveness:** WHO (2008), Nordhaus and Boyer (2000) ✓ Space Heating and Cooling Expenditure. **Costs:** Tol (2002a, 2002b), Bigano et al. (2006), De Cianet al. (2007). **Effectiveness:** Ad hoc assumptions
Generic adaptive capacity → Modelled as an exogenous trend*
✓ Exogenous trend increasing at the rate of total factor productivity
Investment in specific adaptive capacity → Modelled as a "stock" variable*
✓ Investments in specific capacity set to be 1% of world expenditure on education and total R&D in the calibration year. Allocated to regions proportionally to the normalised share of education expenditure over GDP

Source: Bosello et al., (2013)

Table 7: Adaptation costs and effectiveness, for a doubling of CO_2 concentration. Base for the calibration in the AD-WITCH model

	Water in Agric. (irrigation) (Billion $)	Water in Other Vulnerable Markets (Billion $)	Early Warning Systems (Million $)	Coastal Protection (Billion $)	Settlmnts (Billion $)	Cooling Expenditure (Billion $)	Disease Treatment Costs (Billion $)	Adapt. R&D (Billion $)	TOTAL (Billion $)	TOTAL (% of GDP)	Effectiveness of adaptation (% of damage reduced)
USA	3.0	1.3	5	3.57	22.1	3.9	1.13	2.92	37.9	0.09	0.18
WEURO	4.7	2.0	5	5.03	56.2	-8.8	-0.68	2.44	60.9	0.18	0.13
EEURO	7.4	3.2	5	0.26	3.2	-0.8	-0.06	0.03	13.2	0.37	0.30
KOSAU	5.9	2.5	5	1.77	5.2	7.7	1.86	0.29	25.3	0.48	0.16
CAJAZ	1.6	0.7	5	2.87	9.8	-7.8	3.02	1.66	11.8	0.09	0.20
TE	10.1	4.3	5	1.66	3.2	0.6	0.13	0.06	20.1	0.28	0.12
MENA	50.7	21.7	5	1.24	3.9	18.6	2.12	0.14	98.5	1.06	0.34
SSA	13.4	5.7	5	2.68	3.9	10.4	0.51	0.01	36.6	0.70	0.21
SASIA	17.0	7.3	5	1.28	19.7	50.7	1.10	0.04	97.1	0.49	0.19
CHINA	3.0	1.3	5	1.26	17.2	45.5	0.29	0.16	68.6	0.20	0.15
EASIA	1.3	0.5	5	4.26	3.9	25.9	4.74	0.04	40.7	0.40	0.18
LACA	4.3	1.8	5	7.75	5.9	2.0	5.72	0.07	27.7	0.13	0.38

Source: Adapted from Bosello et al., (2013)

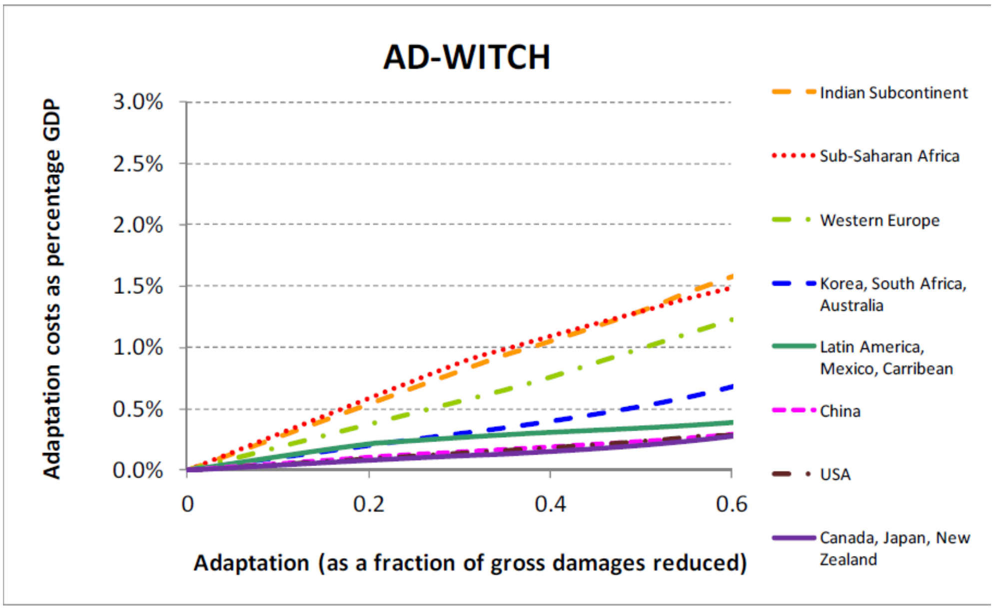


Figure 4 Adaptation cost/effectiveness curves in AD-WITCH

5 Conclusions

This deliverable initially revises the existing literature on cost and benefit of adaptation to verify if the information available would allow to build adaptation functions into the CGE model used within the ECONADAPT project. Results of this scrutiny show that, at best, cost-effectiveness ratios for adaptation in different areas, and in just a subset of countries, can be determined. This information is however highly insufficient to allow the implementation of adaptation functions into a CGE model like ICES that has to be used in the subsequent D8.2 for the analysis of planned adaptation. Accordingly, the calibration of adaptation in the ICES model in D8.2 will be based on a completely different approach: rather than trying highly controversial if not unappropriated extrapolation and generalization from the literature, specific data for adaptation against sea-level rise, and for irrigation are derived from engineering/bottom-up impact models. This process is extensively described in D8.2.

However, to enrich this deliverable, section 3 suggests an in-depth methodology to model adaptation against sea-level rise, while section 4 describes the methodology applied to implement adaptation in to dynamic optimization models.

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Appendix A: Cost-Benefit ratios by sector and impact

Table 8: Cost-Benefit ratios for adaptation measures to cover water availability

ADAPT measure	DATA Level/ GEO coverage	CB-ratios
Improving irrigated agriculture; improving urban water supply; water storage; erosion control.	Kenya.	Yearly: **0.2**
Leakage control	Greece.	
Construction of gabion check dams in the river and construction of earth fill dame in lake	Rupa lake watershed, Nepal.	**0.6** (total costs/net benefit)
Building and adapting infrastructure for municipal and industrial water supply and wastewater treatment.	OECD countries.	**0.7** (total costs/net savings)
Depending on cases.	Gambia.	**0.1** (when synchronized and implemented in tandem with water conservation); **1.2** (all four measures)
Soil and water conservation techniques. Fish ponds.	Lake Chilwa catchment, Malawi.	Soil and water conservation techniques: **0.2**; fish ponds: **0.003** both: **0.15**

Table 9: Cost-Benefit ratios for adaptation measures for infrastructures

Climate Change Impact	ADAPT measure	DATA Level/ GEO coverage	CB-ratios
Heat	Heat-resistant road cover, Adjustment of rail infrastructure to heat	Germany	New road cover: **from 0.9 to 7.5** Adjustment of rail infrastructure to heat: **from 0.7 to 0.9**
Heat	Retrofitting existing rail infrastructure concerning increased temperatures on tracks, Retrofitting existing road infrastructure concerning increased temperature, Retrofitting existing infrastructure of airports concerning increased temperature	EU27	Retrofitting existing rail infrastructure concerning increased temperatures on tracks (avoiding rail buckling): **from 0.6 to 0.5** Retrofitting existing road infrastructure concerning increased temperature (heat resistant asphalt): **from 1.5 to 3.5**
Precipitation	Improved drainage system for roads and airports	EU27	**from 2.6 to 4.3**
Multiple risk	Weather services / forecasts for transport sector	Germany	**from 1.1 to 2.2**

Table 10: Cost-Benefit ratios for adaptation measures for health

Climate Change Impact	ADAPT measure	DATA Level/ GEO coverage	CB-ratios
Heatwaves	Urban Planning	Flanders	CB ratio private : from **0.03** in year 1 to **-1.65** in year 26-50 CB ratio social: from **-4.01** in year 1 to **8.24** in year 26-50
Heatwaves	Heat Health Warning System (HHWS)	Global.	0.0004
Heatwaves	Heat Health Warning System (HHWS)	Rome.	**CB ratio lower than 1**
Food Water Borne	Education & information	Kenya.	**0.33-0.08**
Vector Borne	Vaccination	France.	**-1.77**
Vector Borne	Vaccination	China (Guizhou).	**0.25** (considering only saving from the health budget) **0.04** (considering the societal perspective)

Table 11: Cost-Benefit ratios for adaptation measures for ecosystems

Climate Change Impact	ADAPT measure	DATA Level/ GEO coverage	CB-ratios
Sea-level rise, extreme weather events, flooding	Storm surge barrier	Scheldt Estuary, Belgium & the Netherlands	1.14
	Overschelde		-1.9
	Dyke Heightening		scenario 3a: CB ratio **0.56** scenario 3b: CB ratio **0.53**
	Flood Control Areas		scenario 4a: CB ratio 0.5 scenario 4b: CB ratio 0.44 scenario 4c: CB ratio 0.33
	Controlled Reduced Tidal Areas		0.56
Increased flooding and loss of coastal habitats	Wetland Restoration: habitat creation/ compensation (mudflats; lagoons; salt marshes; coastal grazing marshes; saline lagoons; rotational arable fields). Flood protection (2 Mio m3 of water to enter and leave on higher (i.e. 'spring') tides)	UK	from 2.16 to 3.27
Increased flood risk	Improvements and maintenance of 'hard' coastal defence structures (seawalls and groynes)	Redcar, North-East England, UK	"do minimum": average CB ratio: 0.4 "improve-managed adaptive" : average CB ratio: from 0.9 to 0.2 (according to different percentage of SoP)
Flooding	Land use change and floodplain restoration	Netherlands	1
Sea level rise	Back away	Samoa	0
	Mangrove		0
	Revive reefs		0.1
	Mobile barriers		0.2
	Beach nourishment		from 0.3 with today climate and moderate change to 0.2 with high change
	Sandbagging		0.2
	Flood-adapt contents		0.3
	Relocation		from 0.6 with today climate and moderate change to 0.5 with high change
	Stilts (new)		Todays climate (0.8) ; Moderate change (0.7); High change (0.5)
	Flood-proof buildings infrastructure		from 1.1 with today climate and moderate change to 1 with high change
	Stilts (old)		Todays climate (1.6) ; Moderate change (1.5); High change (1.2)
	Dikes		Todays climate (1.9) ; Moderate change (1.7); High change (1.2)
	Sea walls		Todays climate (1.9) ; Moderate change (1.9); High change (1.4)
	Breakwaters		Todays climate (5.7) ; Moderate change (5.2); High change (4.1)
	Moveable buildings		Todays climate (13.6) ; Moderate change (12.4); High change (9.1)

Table 12: Cost-Benefit ratios for adaptation measures for energy

Climate Change Impact	ADAPT measure	DATA Level/ GEO coverage	CB-ratios
Global Warming	Building improvements and cooling towers.	The Netherlands.	from **41.7** to **50** (for development of cooling towers, only)
Global Warming		Tanzania.	Energy efficiency in manufacturing industry (**-0.08**); Reduce gaspillage at hydro stations (**0**); Gas CCGT (**0.06**); Solar PV (**0.08**); Targeted decrease of T&D losses (**0.08**); Coal (**0.08**); Solar conc. (**0.08**); Big hydro (**0.08**); Gas (GT) (**0.09**); Geothermal with T&D (**0.09**); Raising level of dam (**0.12**); emergency power (**0.13**); Small hydro with T&D (**0.13**); Biomass (**0.16**); Other decrease T&D losses (**0.18**); off-shore wind with T&D (**0.26**); Individual generator (**0.35**); Small hydro in Tanzania (**0.44**); Improve hydro turbine efficiency (**0.51**)
Global Warming	Demand side actions; supply side actions; ecosystem based; full.	Kenya.	demand side **(0.54);** supply side (**-1.58**); ecosystem based (**-1**); full (**-3.2**)

Table 13: Cost-Benefit ratios for adaptation measures for Agriculture

Climate Change Impact	ADAPT measure	DATA Level/ GEO coverage	CB-ratios
Soil degradation	Strip till without cover crops	Germany	0.04 with average erosion rate of 8,7 t/ha/year and 4.6 t/ha/year
	No-till		0.02 with average erosion rate of 8,7 t/ha/year and 4.6 t/ha/year
	Reduced Tillage	UK	from -160 £/ha to -813 £/ha
	Zero tillage		from -110£/ha to -945 £/ha
	Contour Ploughing		from 7 £/ha to 522 £/ha
	Anti compaction measure	EU	0.12
	Use of soil protecting tires	Germany	from 0.18 to 1.16 (according to efficiency of tyres)
	Tire pressure regulation systems		from 0.12 to 0.92 (according to efficiency)
	Subsoiling general (alleviation)	UK	from 9.57 to 0.52 according to type of soil and effectiveness
	Plough (alleviation)		from 7.65 to 1.13 according to type of soil and effectiveness
	Low ground pressure tyres (avoidance)		from 0.7 to 0.05 according to type of soil and effectiveness
	Tracked tractors (avoidance)		from 1.02 to 0.33 according to type of soild and effectiveness
	Controlled traffic farming, CTF (avoidance)		0
water shortage	Drip irrigation for salinization	EU	2.09
	Irrigation	Germany	1.21
	Irrigation	Netherlands	0.82
	Drip irrigation and different degrees of deficit irrigation A: Full irrigation with application of the required irrigation water depth in all the selected crop development stages B: Stress imposed during vegetative stage C: Stress imposed during maturation stage D: Stress imposed during vegetative and maturation stages	Portugal, Sorraia Valley	from 0.74 €/m3 (EWP) to 0.37 €/m3 (EWP)
Cross cutting	Measures for soil protection, not precise	Germany, Sachsen	3.25
	Low soil erosion (level areas, SOM loss only)	EU	0.68
	Erosion control technologies, a combination of all and not specified	USA, for corn	0.18
	Cover crop, Good Agricultural Practice	Barnham, England (NW Europ)	from **0** to **1.7**
	Contour hedges (to combat wind erosion)	Germany	from -5663.41 €/year to -3468.41 €/year

	Green belts (to combat water erosion and runoff)		from 0.49 to 1.4
	Catch crops and under sowing	Germany	from 0.25 to 2.57
	Reduced impact logging	EU	1.46
	Transformation of cultivation on sloping land to permanent grassland and decommissioning (one of the 3 next alternatives)	Germany	from 0.82 to 1
	Erosion control programs (subsidies to strip till) uses the same analysis as for no and strip till and adds individual subsidies to benefits		from 0.35 to 0.27
	Adapted crop varieties	Germany, Sachsen	from 0.001 to 0
	Policy intervention for soil erosion	Austria	0.72
	Policy intervention for soil erosion, not precise	Finland	0.71
	Policy intervention for soil erosion, not precise	France	0.71
	Policy intervention for soil erosion, not precise	Germany	0.69
	Policy intervention for soil erosion, not precise	Greece	0.71
	Policy intervention for soil erosion, not precise	Italy	0.71
	Policy intervention for soil erosion, not precise	Portugal	0.71
	Policy intervention for soil erosion, not precise	Spain	0.71
	Policy intervention for soil erosion, not precise	Sweden	0.70
	Policy intervention for soil erosion, not precise	EU-15	0.71