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SCIENCE FOR A SUSTAINABLE DEVELOPMENT

EVALUATION OF CLIMATE CHANGE IMPACTS AND ADAPTATION RESPONSES FOR MARINE ACTIVITIES

CLIMAR project

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North Sea

FINAL REPORT PHASE 1

EVALUATION OF CLIMATE CHANGE IMPACTS AND ADAPTATION RESPONSES FOR MARINE ACTIVITIES

CLIMAR project

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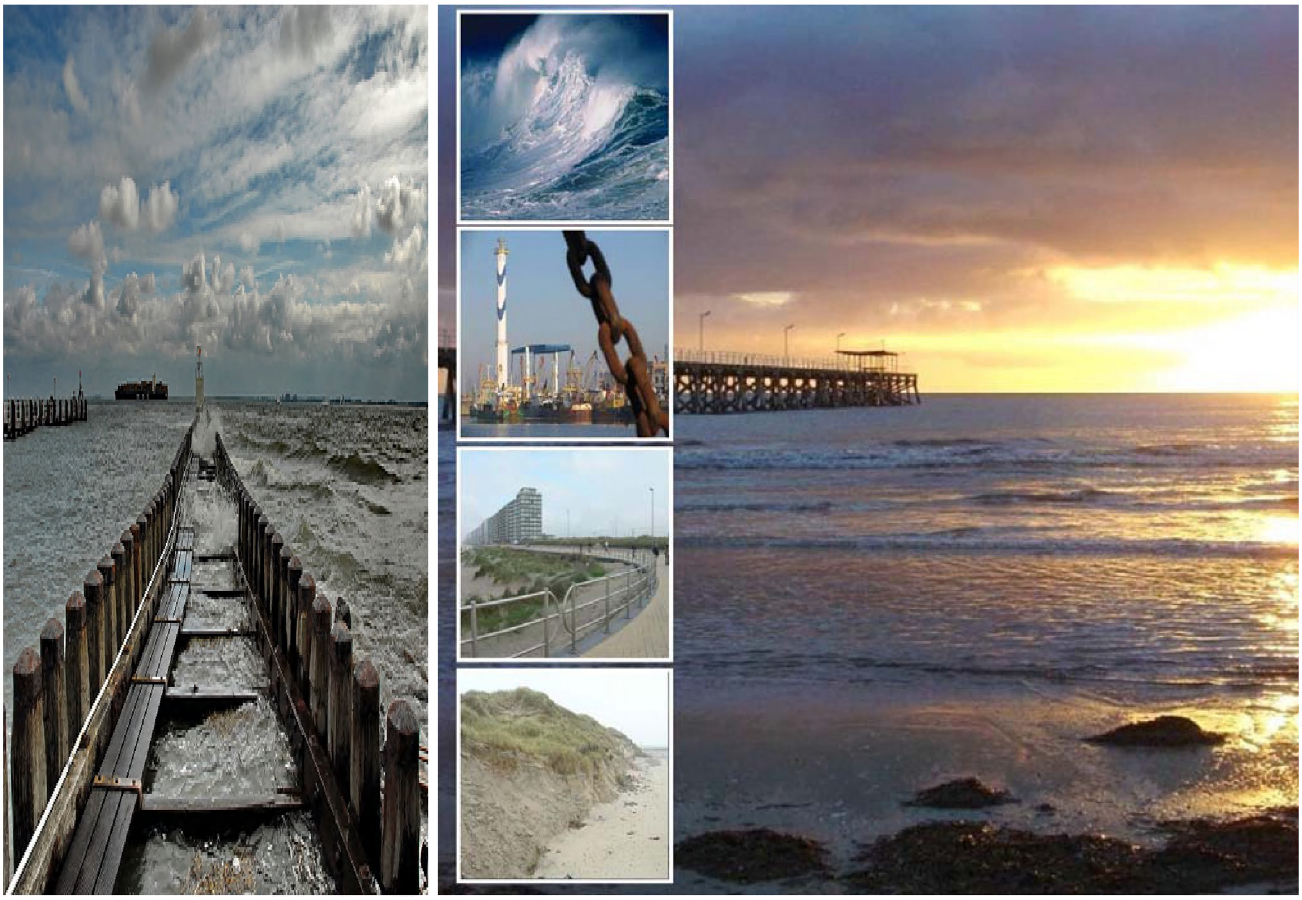

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ABBREVIATIONS

AMFS	Adaptation Measure Fact Sheet
BCS	Belgian Continental Shelf
BMDC	Belgian Marine Data Centre
BODC	British Oceanographic Data Centre
BPNS	Belgian Part of the North Sea
COP	Conference of the Parties
DNMI	Det Norske Meteorologiske Institutt
EC	European Commission
EIA	Environmental Impact Assessment
EU	European Union
GLOBEC	Global Ocean Ecosystem Dynamics
ICES	International Council for the Exploration of the Sea
ICZM	Integrated Coastal Zone Management
IFS	Indicator Fact Sheet
ILVO-Fisheries	Institute for agricultural and fisheries research - Animal Sciences unit - Fisheries
IPCC	Intergovernmental Panel on Climate Change
MDK	Agentschap Maritieme Dienstverlening en Kust, Afdeling Kust
MIRA	Milieurapport Vlaanderen
NAO	North Atlantic Oscillation
UNFCCC	United Nations Framework Convention on Climate Change
PE	Primary Effect
PSMSL	Permanent Service for Mean Sea Level

RIA	Regulatory Impact Assessment
SE	Secondary Effect
SEA	Strategic Environmental Assessment
SIA	Sustainability Impact Assessment
SLR	Sea Level Rise
TAW	Tweede Algemene Waterpassing
WCS	Worst case scenario
WFD	Water Framework Directive
WGCCC	ICES/GLOBEC Working Group on Cod and Climate Change
WGFE	ICES Working group on Fish ecology
WKDRCS	Workshop on the Decline and Recovery of cod Stocks throughout the North Atlantic, including tropho-dynamic effects
WODB	World Ocean Data Base

1 Introduction

1.1 Context

Based on the recommendations of the “Intergovernmental Panel on Climate Change” (IPCC), the Kyoto-Protocol and relevant national strategic documents, scientific research is needed to assess the impact of climate change, specifically on the vulnerable marine ecosystem and its users. While preventive source measures such as cutting greenhouse gas emissions are necessary to tackle the problem at long term, adaptive measures are necessary to cope with the primary and secondary impacts of climate change in the North Sea. Furthermore, instruments are needed to evaluate the adaptation measures on their sustainability, their impact on marine activities and their relation with preventive measures and sectoral policies.

The North Sea plays an important role in our country’s cultural, social, and economic well-being. The North Sea Ecosystem is characterised by high productivity and highly diversified habitats but also by heavy ship traffic, intensive fishery, a number of offshore activities such as oil and gas extraction, the presence of cables and pipelines, sand and gravel extraction, dredging activities, and in the near future, the presence of wind turbine parks. This intensive use has as a consequence that the vulnerability of the ecological, social and economic community formed by the North Sea is high (in terms of risk on damage) for climate change. This calls for a sustainable approach when addressing climate change issues in our North Sea.

The effects of climate change on marine systems are manifold. Sea level rise is an important indicator of climate change in coastal regions. It increases the likelihood of storm surges, coastal erosion, landwater salt intrusion, endangers coastal ecosystems, etc. Changes in the sediment transport cycles will occur and cause, together with the changing hydrodynamic conditions, secondary effects, *e.g.,* on dredging activities, marine transport and harbour activities. Ocean warming can increase zoo- and phytoplankton productivity (CO_2-uptake), increase risks for human health, change the marine species composition, stress the fishery activities, etc.

It is obvious that the marine ecosystem has a certain autonomous adaptation capacity to counter these effects. On the other hand, some secondary effects will have synergetic or contradictory results. Adaptive scenarios developed by an individual sector could influence another part or user of the marine environment.

1.2 Objectives and expected outcomes

The objective of CLIMAR is the elaboration of an evaluation framework for adaptation scenarios/measures as a response to climate induced ecological, social and economical impacts and this for the Belgian North Sea environment.

The objectives can be synthesized as follows:

- Definition and modelling of climate change induced primary impacts at North Sea scale: sea level rise, increased storminess, possible increased rainfall, temperature, etc.
- Deduction of climate change induced secondary impacts for both the marine ecosystem and related socio-economic activities:

  - Identification and classification of secondary impacts on the marine ecosystem in general and for related socio-economic activities with the focus on two case studies (sectors):
    - modelling of the climate induced secondary impacts related to coastal flooding;
    - assessment of the climate induced impacts on the fisheries sector.
- Identification of adaptation scenarios/measures for both case-studies and using these for extrapolation towards the marine ecosystem in general and to related socio-economic activities.
- Development of an evaluation framework, based on both case studies, to assess the effectiveness of the identified adaptation scenarios/measures for each specific marine activity.
- Evaluation of the effects of the proposed adaptive strategies, focusing on the embedding of these strategies in the global climate change policy, their practical integration in the current policy and legislative framework and possible implementation problems.
- Formulation of recommendations towards North Sea future policy and its different socio-economical activities. Based on the two case studies, coastal flooding and fisheries, on the one hand and the parallel integrated assessment and policy and legal evaluation on the other hand, recommendations will be formulated for North Sea future policy and its different socio-economic activities.

It is clear that this project will provide a valuable output for climate change policy for the North Sea. This output will consist both of practical tools (modelling, assessment) as well as quantified results and applications.

2 Methodology

CLIMAR aims to determine and evaluate in detail the effects of climate change and possible adaptation scenarios in the North Sea, focusing on the Belgian Part of the North Sea (BPNS), both on a regional (Belgian Part of the North Sea) and sectoral scale:

- Regional scale: some strategies will be relevant for several sectors or for the North Sea environment as a whole.
- Sectoral scale: following coastal and marine sectors have been selected to examine the climate effects in more detail:
  - coastal infrastructure (case study);
  - fishery (case study);
  - others: tourism, shipping and harbour related activities, energy supply and sand and gravel extraction.

In general, 4 steps can be distinguished in the adaptation process to climate change:

- Scoping the impacts;
- Quantifying the risks;
- Decision making and action planning;
- Adaptation strategy review.

2.1 Scoping of the impacts

In a first step the main impacts of climate change that are expected for the Belgian Part of the North Sea are identified, as well as the translation of these impacts towards the different marine sectors. For the different sectors one wants to know:

- How will climate change?
- What are the climate impacts on the sector?
- Could there be indirect climate impacts too?
- Are climate impacts important to the sector?
- What are the priority climate risks?
- Will climate impacts be more or less important than the other risks the sector faces?

This has been translated in the following work packages.

2.1.1 Definition and modelling of climate change induced primary impacts at the North Sea scale – Identification

A first step in CLIMAR has been to differentiate the primary impacts of climate change from the natural evolution at the North Sea scale and to select the most relevant ones:

- Hydraulic impacts: determination of sea level rise, change of storminess, change in hydrodynamic climate (flooding).
- Impacts on erosion and sedimentation: change of erosion and deposition patterns (*e.g.,* siltation).
- Physical, chemical and ecological changes: change of temperature, salinity, nutrients and algae blooms.

2.1.2 Deduction of secondary impacts both on the marine ecosystem as well as on other socio-economic activities – Identification

Secondary impacts as defined in the proposal are those derived from primary impacts. Secondary impacts of climate change have been deduced at the regional, as well as at the sectoral scale:

- Regional: Based on a study of primary impacts assessment, secondary impacts on the marine environment are identified for the Belgian coastal and marine waters. A global literature study has been conducted to identify all secondary impacts. They were classified according to their ecological, social and economical nature.
- Sectoral: Climate change will affect different sectors in a different way. On the other hand, within a specific sector, differences can be observed depending on the activity considered. One sector can thus be divided into several subsectors (only when relevant). Secondary impacts (ecological, economical and social) have then been worked out in more detail per subsector.

2.2 Quantifying risks

This step examines in more detail the magnitude of the primary impacts and the impacts on a sector and is important to decide on adaptation strategies for the North Sea ecosystem. The following questions have to be answered at this step:

- What is my attitude to risk?
- How significant are the climate risks on the sector?
- How do these compare to the non-climate risks?
- How much could climate impacts cost?
- Do I need to adapt to climate risks?
- How confident am I about the assessment?

Compared to “Scoping the impacts”, here a quantitative completion of the questions occurs.

2.2.1 Definition and modelling of climate change induced primary impacts at the North Sea scale – Quantification

2.2.1.1 Quantifying the primary impacts

To establish these primary impacts, three different methodologies have been used in the project: literature study, statistical analysis of time series and numerical modelling.

It is clear that global climate change is an extremely complex matter, involving many different aspects and disciplines. The IPCC has published in the course of 2007 the ‘4th Assessment Report’ (IPCC, 2007), which discusses in length the different effects which could be expected. Many different publications can be found in the literature on the subject. Although there is general agreement on the fact that effects are to be expected, the uncertainties remain, however, very high. Furthermore, the regional differences can be significant.

A method to determine the primary impacts of the climate changes is statistical analysis of time series. Data series of sea level, waves and wind speeds and wind directions can be used to determine the sea level rise and the changes in storminess for the Belgian coastal waters. Different statistical models (linear trend, accelerated trend,…) can be used to fit the data and to get more insight in the observed changes. Data series of sea water temperatures will be analysed to get information on the increase of the sea water temperature, a parameter of importance, *e.g.,* for the fisheries.

To evaluate the primary impact of global climate changes, numerical models can also be used. Different numerical models are available: hydrodynamic models, wave models and sediment transport models. These models can be run to simulate the current situation and to assess, *e.g.,* the maximal bottom stress or amount of mud, deposited at the bottom. The changes of these parameters, under the influence of the climate induced changes, *e.g.,* sea level rise or increased wind speed, can be assessed.

2.2.1.2 Climate change scenarios

As there remain many uncertainties about how much climate change will happen, a range of climate change scenarios has been developed. Both mid- and long-term scenarios will be drawn based on both comparable literature studies of neighbouring North Sea countries and on the modelling results for the Belgian Part of the North Sea.

2.2.2 Deduction of secondary impacts both on the marine ecosystem as well as on other socio-economic activities – Quantification

2.2.2.1 Quantitative description of the marine sectors

Quantification of the secondary impacts will take place on a sectoral scale. To be able to do this a good insight in the sector is necessary. Each sector (and its subsectors) has therefore been described in a separate subdocument including definitions, intensities and geographical location, socio-economical importance and the most important external factors influencing the sector.

2.2.2.2 Socio-economic scenarios

As a result of this description, some socio-economic factors (external factors) can be identified that will have to be incorporated into the quantification step if a more realistic outcome is intended. So besides the climate change scenarios, socio-economic scenarios will be developed to deal with the uncertainties of quantification.

2.2.2.3 Quantifying the secondary impacts

2.2.2.3.1 General

The secondary impacts (direct and indirect) were primarily quantified in more detail for two sectors (case-studies): coastal infrastructure and fisheries. With its close connection to the environment and climate itself, tourism was considered as a third highly climate-sensitive economic sector for the BPNS.

For the quantification of the secondary impacts an indicator approach (Figure 1) has been chosen. An indicator is a variable or measure describing a “key-element” (here the main ecological/ social/ economical effects) of the system. The indicator takes into account both the element at risk (*e.g.,* number of tourists) and their vulnerability (*e.g.,* mobility, protection status by existing adaptation measures, etc.). Indicators are being worked out for the most significant climate risks (high priority score).

Based on the climate change scenarios and taking into account the socio-economic scenarios, the impacts were quantified according to the methodology presented in Figure 2.

Two case-studies were studied in more detail: the identification of climate induced secondary impacts on coastal infrastructure and on fisheries. Tourism was considered as a third important sector with respect to climate change.

2.2.2.3.2 Coastal flooding

In the case-study of coastal infrastructure, the most important primary impacts of climate change are sea level rise and increased storminess (increase in frequency of storms, higher storm surges and increase of wave height during storms). The direct consequences of these physical phenomena are events like flooding and increase in coastal erosion. In combination with increasing human settlement

and infrastructure developments in the coastal zone, considerable ecologic, economic and social consequences can be expected. For each effect category one main indicator has been selected to be developed quantitatively by means of a set of numerical models.

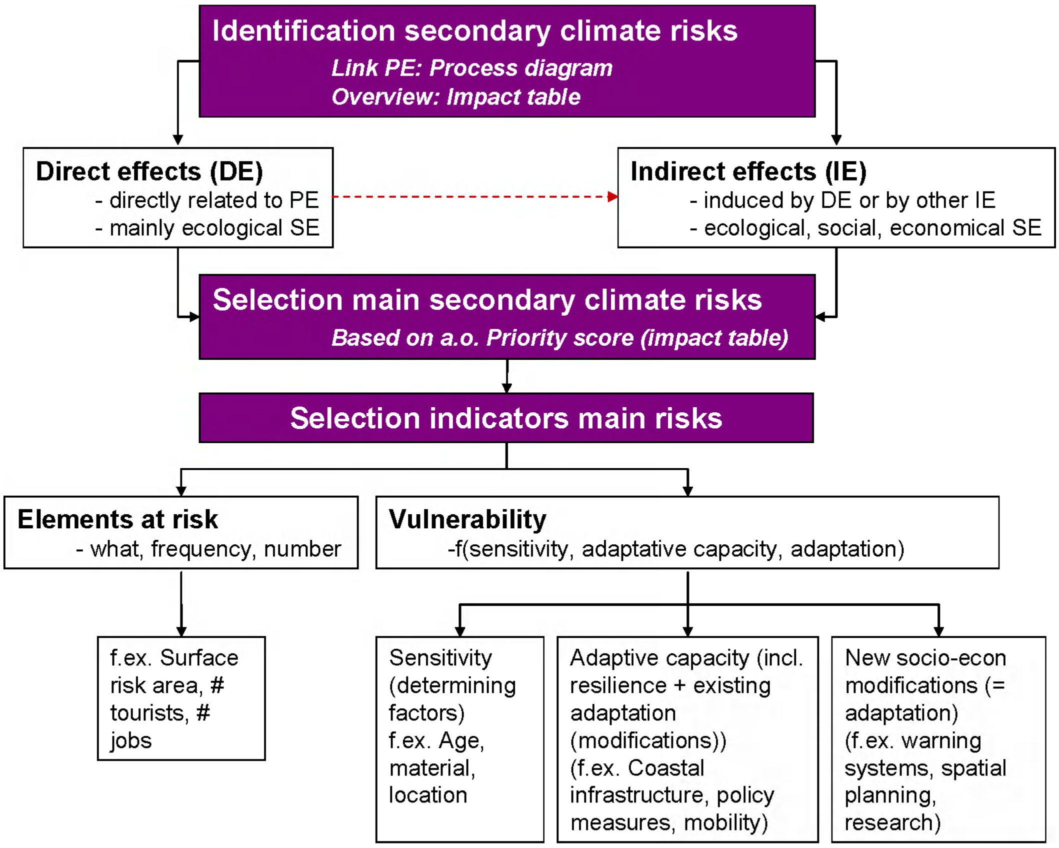

Figure 1: Indicator approach

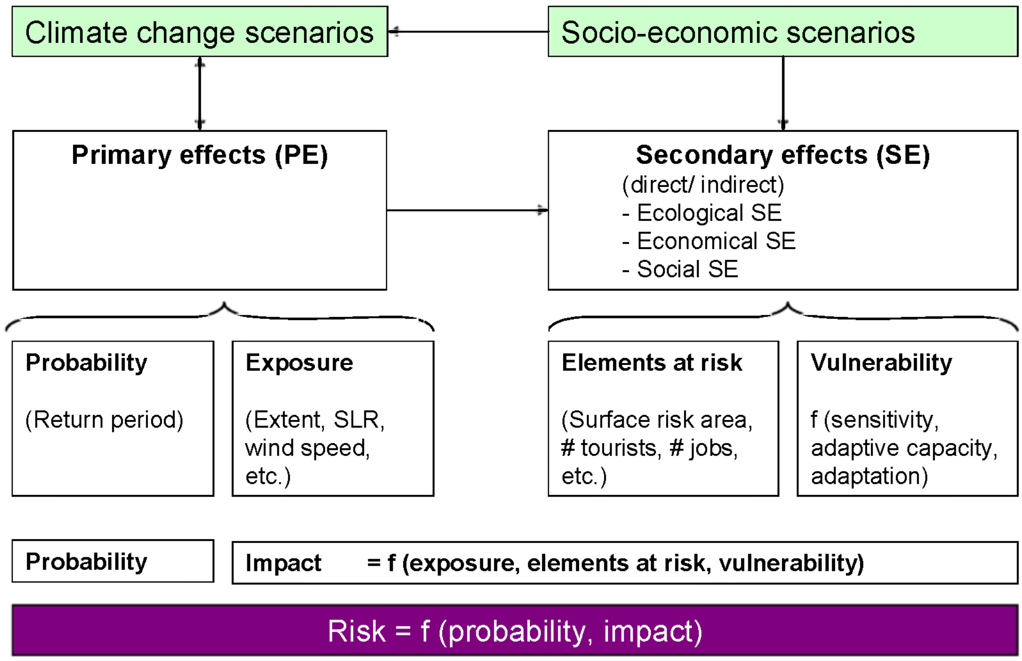

Figure 2: Quantification of climate impacts

2.2.2.3.3 Fisheries

Climate change can impact the Belgian sea fisheries indirectly via the fish stocks, the natural resource fisheries depends upon, and directly via the (weather) conditions in which the vessels have to operate. Therefore, three main elements which interact with each other, namely climate, stocks and sector/fleet, have been identified and their interactions have been described.

In the case-study of fisheries the most important primary impact is the increase of the water temperature as this parameter influences fish stocks on different levels and via different pathways. Temperature can have a direct and/or indirect effect on individual fish, stock(structure), food web and ecosystem causing a change in distribution and or abundance of (potential) commercial fish stocks. The effect of climate change on fish stocks is very complex and sufficient long-term data sets, suitable models, specific expertise and ample time are indispensable to perform the analyses needed to predict effects of climate change on fish stocks. Within the framework of CLIMAR it was opted to base the identification and quantification of the secondary impacts relevant for Belgian fisheries on a literature study and modelling work currently undertaken by several (ICES) scientists and working groups.

2.2.2.3.4 Tourism

The quantification of the secondary impacts for coastal tourism was mainly based on available literature including indicator studies on tourism, sector reports, and expert interviews. Besides the impacts on coastal tourism is highly linked with the effects determined in the case study coastal flooding. Based on the model results the flood risk area will be determined affecting also coastal tourism (*e.g.,* beach area at risk).

2.3 Decision making & action planning (adaptation)

2.3.1 Adaptation

Adaptation means to take action either to reduce the chance of a hazardous event happening, or to reduce the magnitude of its consequences. A difference can be made between autonomous adaptation (actions taken naturally by private actors) and policy-driven adaptation (result of deliberate policy decisions).

This step will assess the need for adaptation, and which adaptation strategy is most appropriate. Therefore, the following questions should be answered.

<u>Decision making:</u>

- What is my attitude to the risk? Is the risk acceptable or not? For this purpose, the critical threshold of the effect should be quantified. This threshold can be abrupt (*e.g.,* wave height leading to flooding) or gradual (*e.g.,* temperature increase). The threshold may be a natural property of the system, but often thresholds are socially constructed based on risk attitude, like the 1 in 1000 year return period for coastal floods.
- How do these risks compare to the non-climate risks? Check the degree of change due to changes in external factors (socio-economic scenarios).
- How much do climate impacts cost? It is useful to know the costs of climate impacts to be able to compare them to the costs of adaptation measures, to work out how much adaptation is needed. Once the climate risks have been quantified, guidelines can be used to convert the risks into financial costs. At this moment there is not much information on which to rely.
- Do I need to adapt to climate risk? If the risk assessment shows a significant risk, or that climate could exceed critical thresholds for the system, then adaptation is needed.

- How confident am I about the assessment? There is still a lot of uncertainty about the magnitude of climate change and the way the system responds to the different changes. The degree of confidence in the assessment will also determine the decision for specific adaptation strategies.

Action planning:

- How to adapt to climate risks?
- What level of adaptation is required?
- What adaptation strategy is most appropriate?
- What is the relation between a sectoral strategy and an integrated strategy?
- What will happen in case of over- or under-adaptation?
- When is it necessary to take action?
- How to minimise the cost of adapting?

2.3.2 General identification of adaptation measures

A first step will be the identification of all possible adaptation measures (both structural and non-structural) as a response to the secondary impacts. Initially the focus will be on actions to manage the priority risks identified through the earlier steps (see 2.2.2). These risks will be subjected to the questions defined under "Decision making".

The most suitable adaptation measures ("Action planning") will depend on the nature of the risks and the attitude to the climate risk. The effect (risk reduction) of each measure is the key parameter. This will be investigated, taking into account the possible side-effects and interrelationships of adaptation and the natural adaptive capacity of the ecosystem. The goal is to find no-regret adaptation options and win-win options.

Adaptive measures will be worked out per sector and specific linkage will be made to secondary and primary impacts. As different measures are taken only partly because of climate change impact (*e.g.,* enforcement of coastal protection would also be considered without climate change induced risk), an attempt will be made to differentiate the specific effect caused by the extra potential of measures aimed at climate change impact reduction.

The identification of alternative adaptation measures will benefit from the partnership of CLIMAR as it creates a discussion platform. The same is true for the interactive workshops organised per sector (public participation).

2.3.3 Identification of adaptive strategies

Finally, the measures will be combined as sectoral adaptive strategies. A climate adaptation strategy represents a combination of measures and options chosen to meet a particular risk (European Environment Agency, 2004). The strategy should increase the robustness of long term (infrastructure) investments, enhance the adaptability of vulnerable natural systems, improve societal awareness and preparedness, increase the flexibility of vulnerable marine activities (*e.g.,* ease of change of activities or locations). The success of the full strategy depends on numerous factors such as the effectiveness of the measures, the acceptance of the introduction, the potential for benefits that outweigh the costs, the consistency of the measures with other sectoral initiatives, etc.

These strategies or combination of adaptive measures will serve as the base for evaluation. They will not only be based on literature review but will be confronted with sectoral opinions by means of interviews. Hence the adaptive strategies should be not in contradiction with the global economical development strategy of a marine sector or the natural marine ecosystem evolution.

2.4 Adaptation strategy review

The most important questions to be answered are:

- Do we have a sensible adaptation strategy?
- How often should the strategy be reviewed?
- Should the strategy be changed or updated to be able to meet the goals?

2.4.1 Evaluation of adaptation strategies

In order to stimulate the abovementioned preconditions for the sectoral adaptation strategies, an evaluation framework will be developed that can assess the value of the scenarios for each specific marine sector. The evaluation tool (multi-criteria analysis) will be based on the principles of sustainable development and scores both economical, ecological and social merits and damages of the adaptation strategy. Hence the adaptation strategies have to undergo a sustainability test. Full use will be made of the case-studies for "coastal flooding" and for the "fisheries sector", as well as – from a methodological point of view – the elaboration of an assessment framework during the ADAPT project (Giron *et al.*, 2008) .

2.4.2 Policy and legal evaluation of adaptive strategies

The legal approach for this research is twofold. On the one hand, there is research into the legal evaluation of adaptation measures and on the other hand, there is research into the legal evaluation of the adaptive strategies. In order to be able to evaluate the proposed adaptation measures and adaptive strategies a list of the relevant policies and legislation with implications for adaptation measures and strategies has to be made. Nowadays environmental legislation is to a large extent determined by international and European (soft and hard) law, which is, in Belgium, transposed and implemented at the regional level, although the federal government retains important prerogatives. Furthermore adaptation measures against climate change are rarely "stand-alone" environmental measures and therefore the involvement of several other legislation and policy sectors on different levels is often required. In this respect the relevant legislation must be assimilated from a wide variety of legal categories including European and International law and additional national legislation and policies. The list of the relevant legislation will ensure that a legal framework can be established for the proposed adaptation measures. It will be investigated to what extent use has to be made of existing tools such as Environmental Impact Assessment (EIA).

Starting from the total climate change policy (UNFCCC, IPCC, EU and further implementation on a national level), the international and national legislative framework, including issues regarding Integrated Coastal Zone Management (ICZM), as well as strategic documents formulated by all socio-economic marine related sectors, but also using results from the global evaluation tool and the case-studies, the adaptive strategies against secondary climate change impacts will be evaluated. It will be investigated to what extent use can be made of existing tools such as Regulatory Impact Assessment (RIA), Strategic Environmental Assessment (SEA) and Sustainability Impact Assessment (SIA). Regarding the latter, use will be made of the results of the Federal Science Policy research Project "Methodology and feasibility of SIA. Case: Federal Policy-making Processes" which ended in February 2006. To enable a thorough evaluation of the adaptive strategies, the international policy on adaptation must be examined as well as the international legislation, mainly EU legislation which can influence the development of an adaptation strategy (*e.g.,* Marine Strategy Framework and Flood Directive). It is also useful to look at the development of adaptation strategies in other northwest European countries (United Kingdom, Ireland, The Netherlands and France) who face similar climate change impacts. Moreover, there will be an investigation into how these other countries already implement adaptive strategies in their policies and legal instruments, which adaptation measures they propose and assess the advantages and disadvantages. Recommendations will be formulated on the effect of the adaptive strategy, the embedding in the global climate change policy as well as the practical integration of this strategy in the current policy and legislative framework.

2.5 Recommendations

Based on both case studies on the one hand and the parallel integrated assessment and policy and legal evaluation on the other hand, recommendations will be formulated on the effect of the adaptive strategy, the embedding in the global climate change policy as well as the practical integration of this strategy in the current policy and legislative framework.

It is clear that this project will provide a valuable output for climate change policy for the Belgian Part of the North Sea. This output will consist both of practical tools (modelling, assessment) as well as quantified results and applications.

3 Primary impacts

3.1 Definition and modelling of climate change induced primary impacts at the North Sea scale – Identification

The primary impacts of climate change mainly concerns temperature, sea level, storminess and ocean circulation patterns. Climate change will also have an indirect impact on the flooding due to sea level rise as well as to storm surges, and to coastal erosion. Furthermore, it will also affect chemical parameters of the North Sea by a modification of its carbon budget that will result in an acidification of the seawater.

3.2 Definition and modelling of climate change induced primary impacts at the North Sea scale – Quantification

Three different methodologies have been used to quantify these impacts for the Belgian Part of the North Sea: literature study, statistical analysis of measurements and numerical modelling.

3.2.1 Literature study on physical and chemical parameters

Coupled atmosphere-ocean general circulation models are used to produce climate projections for centuries, and to simulate the response of several climate variables to different scenarios for greenhouse gases emissions. However, they are designed to resolve phenomena of several hundred kilometers, and are no more reliable below this scale. As a result, regional coastal systems are not resolved sufficiently in these models. Downscaling techniques, based on statistical relationships between global and regional parameters are therefore required to resolve climate change for regional systems. However, clear relations between local key processes and large scale climate variability are difficult to obtain. Further problems occur because a changing climate may cause changes in the statistical relationship between global and local parameters. The assessment of local impacts is therefore very difficult. A way of dealing with the uncertainties is to draw a series of plausible climate change scenarios.

The primary impacts of climate change mainly concerns temperature, sea level, storminess and ocean circulation patterns. Climate change will also have an indirect impact on the flooding due to sea level rise as well as to storm surges, and to coastal erosion. Furthermore, it will also affect chemical parameters of the North Sea by a modification of its carbon budget that will result in an acidification of the seawater.

For the period 1978-2002, there has been an increase in the sea surface temperature of the North Atlantic of 0.3 - 1 °C, however small areas show a cooling trend. The annual mean wind speed averaged over the North Sea seems to be increased by 10 % between 1960 and 2000. Analyses of past climatic conditions in the North Sea show anomalies in the wind forcing for the past decades: increases in wind strength as well as changes in its direction. The potential impacts of sea level rise are great and unevenly distributed across the globe. Low elevation "hot spots" in Europe included the Belgian coast, which in significantly threatened, even for a 2 m increase in sea level.

In Ponsar *et al.* (2007), more information on this literature study is presented, summarising the actual knowledge on the changes of hydraulic and physical parameters in the southern North Sea, as an effect of climate changes.

3.2.2 Literature study on ecological parameters

The most productive areas in the oceans are the shallow continental shelves (water depth less than 200 meters). They make up for less than 7 % of the ocean's surface but the greatest proportion of primary and secondary production takes place there and they are the most productive fishing grounds.

They are also the areas the most intensely affected by the impacts of climate change. Moreover, coastal systems play a critical role in protecting the coasts from flooding and erosion (Schubert *et al.*, 2006).

The response of marine ecosystems to climate change is dependent of many intricate factors. In addition to natural spatial and temporal variability in the effects of climate change, other factors such as fishing and physical oceanographic factors affect the abundance and distribution of species. The difficulty in identifying the cause of these effects is complicated by buffering (many fish, marine mammals, seabirds and some benthos are long lived and therefore the effects of oceanographic conditions may be buffered at the population scale and integrated over time) and by complex life histories (with eggs, larvae, juveniles and adults often in different places both geographically and in the water column). Moreover, the abundance and distribution of species is affected by other factors such as eutrophication, pollution, diseases and introduced species. The ecological responses to climate change may be partially or wholly hidden by other factors such as fishing pressure and habitat alteration.

In addition to the specific characteristics of a region, the response of marine systems to climate changes depend on other human induced changes in the marine environment; for example, fishing has reduced the number of large fish at high trophic levels whilst increasing agricultural and household activities have resulted in nutrient enrichment of many coastal waters (Philippart *et al.*, 2007).

Causal attribution of recent biological trends to climate change is thus complicated because external factors (non climatic influences) dominate local, short term biological changes.

The increase in surface ocean CO_2 has consequences for the chemical equilibrium of the ocean which is becoming more acidic. It has also impacts on marine organisms using carbonate to produce shells consisting of calcium carbonate $CaCO_3$.

Climate change is predicted to have direct and indirect effects on marine plants and animals and consequently on marine food webs. Firstly, changes in temperature will directly affect metabolic and developmental rate in many animals, and processes such as photosynthesis and respiration in plants. Secondly, changes in mean annual temperature will affect change in isotherms and consequently in the distribution of marine organisms. Thirdly, alteration of life cycle events that are triggered by environmental clues related to climate may lead to decoupling of trophic interactions. Fourthly, species with short generation times and rapid population growth rates might be able to adapt to new environment as the result of evolutionary change.

The ecological changes that have occurred in the North Sea in the late 1980s and 1990s are sufficiently abrupt and persistent to be termed “regime shift”. This regime shift has a profound impact on the North Sea ecosystems. These impacts range from altered hydrodynamic characteristics, step-wise changes in nutrient ratios and pronounced changes in the abundance, composition and distribution of plankton. There are ample evidences of shifts in biogeographical distribution and abundance at different trophic levels: in phytoplankton, zooplankton, benthos, and fish species. For example, a northward shift in Atlantic cod is reported, while densities in monkfish remained constant. The population in haddock decreased in density in the southern part of the North Sea but increased in the northern part. Evidences of correlations of distribution of seabirds with sea temperature are also reported for the Atlantic puffin, the black legged kittiwake and the northern fulmar.

Over the last decades, changes of phytoplankton species in the northeast Atlantic have created anomalous phytoplankton blooms with harmful consequences on humans and on the surrounding ecosystem. Toxic material released from these blooms are causing mass mortalities of marine organisms, as well as affecting human health through contaminated shellfish and fish populations. Global climate change expressed as an increase of the summer temperature maximum by 4 °C in

2100, in combination with water column stratification, led to a doubling of growth rates of potentially harmful algal blooms. However, the wide ranges of uncertainties in the projected increases in temperature and precipitation associated with climate change, and the impossibility to take into account the effects of temperature and stratification changes on ecological processes that are important in phytoplankton species prevents a quantitative assessment of the risk of harmful blooms.

More information on this literature study can be found in Ponsar *et al.* (2008).

3.2.3 Data analysis

A second method to determine the primary impacts of the climate changes is statistical analysis of time series. First a trend analysis of the mean sea level was performed. Further an analysis of wave measurements and wind measurements on the Belgian Continental Shelf was used, to get some information on the changes on the storminess. At last measurements of the sea surface temperature on the entire North Sea were analysed.

3.2.3.1 Trend analysis of relative mean sea level at Oostende

The goal was to get the longest times series possible for different parameters at the Belgian continental shelf. The hourly water levels of the sea level at Oostende for the period 1980-2006 and the high and low waters at Oostende for the period 1925-1979 were received from the Agentschap Maritieme Dienstverlening en Kust (MDK), Afdeling Kust. Furthermore, monthly and yearly mean water elevations at Oostende were downloaded from the server of the Permanent Service for Mean Sea Level (PSMSL) for the period 1937-2003.

The different water levels (hourly, yearly, high and low waters) were reduced to the same reference level, and their quality was checked. Finally, all available data were combined to construct a time series for the yearly mean sea level for the period 1927-2006. Unfortunately, some gaps are still present in the time series: years 1930, 1940-1942, 1944 and 1950 are missing.

Up to four models have been fitted to the data (Figure 3). With the conventional linear regression, we get a sea level rise (SLR) equal to 1.69 mm yr^{-1}. This SLR is greater than those reported in previous studies (Van Cauwenberghe, 1995; 1999). This SLR is quite surprisingly very close to the value (1.70 mm yr^{-1}) reported by the IPCC for the global average sea level rise (Bindoff *et al.*, 2007). A piecewise linear model suggests a change of SLR in 1992. Prior to 1992, the slope is equal to 1.41 mm yr^{-1} and after it is equal to 4.41 mm yr^{-1}. The latter is remarkably close to the global average rate of 4.0 mm yr^{-1} obtained by Holgate and Woodworth (2004) for the period January 1993 to December 2002 from tide gauges data. A decade-long satellite altimetry data set shows that sea level has been rising at a rate close to 3 mm yr^{-1} since 1993 (Bindoff *et al.*, 2007). With a second order polynomial model, we get a slope varying between 0.72 mm yr^{-1} in 1927 and 2.63 mm yr^{-1} in 2006. The acceleration of the SLR is equal to 0.012 mm yr^{-2} which is almost equal to that (0.013 ± 0.006 mm yr^{-2}) estimated by Church and White (2006) for the global mean sea level. The last model, a 3rd order polynomial model, indicates the SLR might have been sometimes in the past as large as it is today.

Further details on this trend analysis are given in Ozer *et al.* (2008).

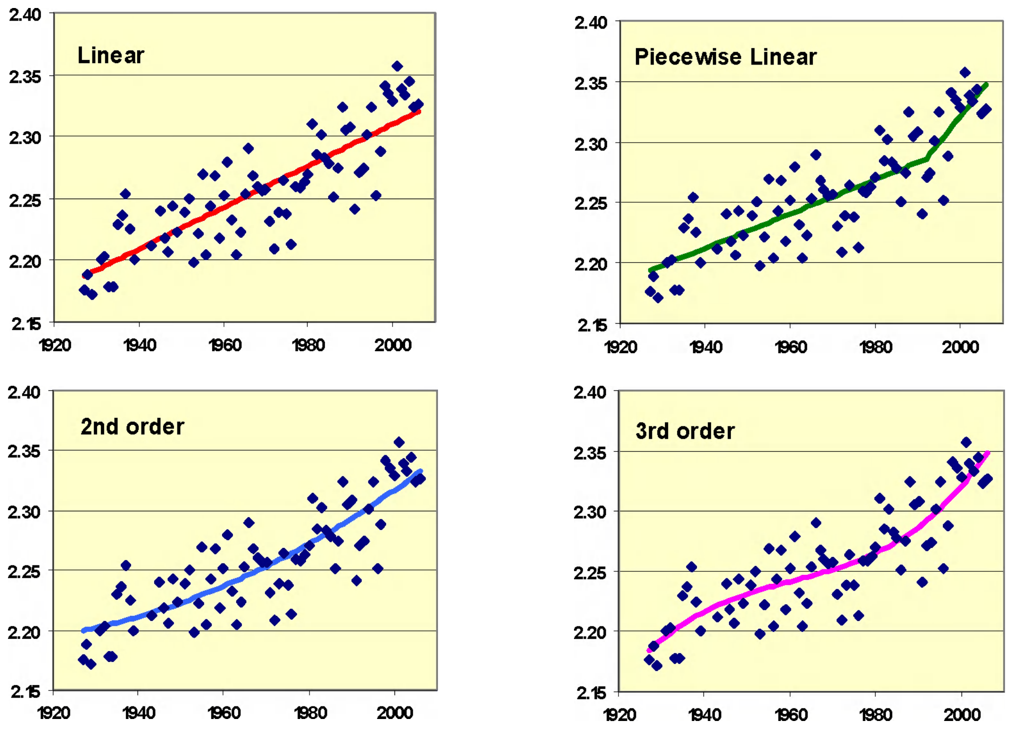

Figure 3: Trend analysis of relative mean sea level at Oostende over the period 1927-2006. (Top left: linear regression; top right: piecewise linear; bottom left & right: 2nd order and 3rd order polynomial models)

3.2.3.2 Data analysis of waves and wind measurements

Measurements of waves and wind were obtained from MDK and were downloaded from the website of Hydro Meteo Centrum Zeeland. The longest time series extends from 1978 till 2007. Furthermore the meteorological forecasts of the Det Norske Meteorologiske Institutt (DNMI) were received for the period 1955-2006. From these meteorological fields, the time series at Westhinder was extracted for analysis.

To obtain uniform time series, the monthly mean of the parameters were calculated. These monthly mean time series then were split in a long term trend, a seasonal cycle and the residue, following the methods, proposed in the NOWESP project (Visser *et al.*, 1996). The long term trend was calculated on the basis of a moving average filter, with a period of 48 months. Gaps in the monthly mean time series were interpolated, taking into account the long term trend and the seasonal cycle. Apart from the extraction of the long term trend, also a simple linear regression was calculated to assess the overall trend in the monthly mean time series.

In Figure 4a, the long term trend is presented for the significant wave height at four stations in Belgian and Dutch coastal waters. A clear variability is apparent with a period of about 7 years, with higher waves around 1987, 1994 and 2001. The period is related to the variation in the North Atlantic Oscillation (NAO), which shows variations with periods of 17 years, 7.7 years and 2.4 years (Loewe and Koslowski, 1994). A clear long term trend is not visible in the significant wave heights. The linear regression shows a small decrease of -0.0013 m yr^{-1} and -0.0027 m yr^{-1} at Bol van Heist and Brouwershavensche Gat 2 respectively, and a small increase of 0.0024 m yr^{-1} at Scheur West.

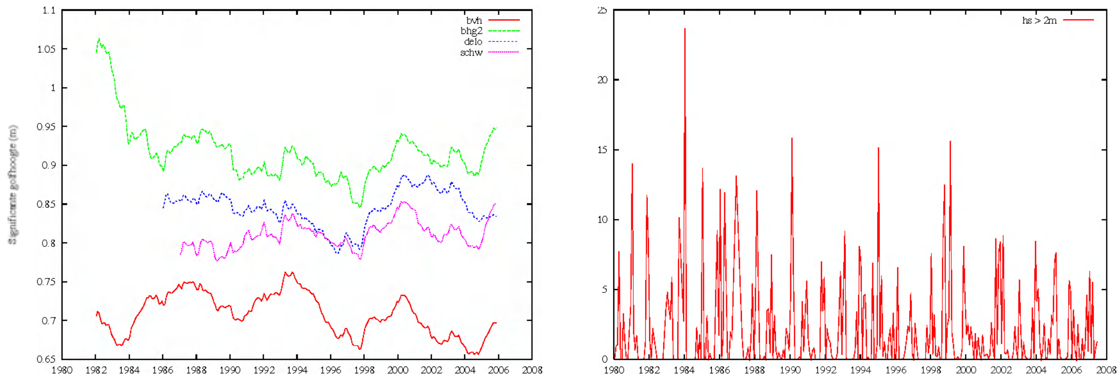

Figure 4: (a) Left: Long term trend of the monthly mean significant wave height at four measuring stations Bol van Heist (bvh), Brouwershavensche Gat 2 (bhg2), Deurloo (delo) and Scheur West (schw) for the period 1980-2007. (b) Right: Percentage significant wave

For most stations a small decrease is found in the percentage of waves higher than 2 m or higher than 3 m (Figure 4b). At the station Brouwershavensche Gat 2, the percentage waves higher than 2 m decreases from 8.4 % in 1980 to 4.6 % in 2007. The maximum wave height during a month increases marginally for the stations Bol van Heist and Scheur West, but decreases for Brouwershavensche Gat 2 and Deurloo. Overall, no clear trend can be found in the significant wave height at the Belgian Continental Shelf. The small tendency for lower waves needs to be confirmed.

In the long term trend of the wind speed at Westhinder, extracted from the meteorological prediction of DNMI (Figure 5a) an increase in monthly mean wind speed could be observed between 1955 and 1968, after which a small decrease of monthly mean wind speed occurs. This decrease in wind speed is till more apparent since the period 1990-1995. The decrease in wind speed agrees with the small decrease in significant wave height at the BCS. Remark that analysis of the (too) short time series at the measuring stations, especially at Westhinder, could give misleading conclusions.

For the maximum wind speeds and the percentage of wind speeds higher than a certain threshold, the results are less clear. The linear regression doesn't show consistent results for the different stations and for the different thresholds used. As an example the percentage of wind speeds higher than 8 Bft. are shown in Figure 5b for the wind speed at Westhinder, extracted from the meteorological prediction of DNMI. Here an increase in percentage seems visible for the period 1955 till 1990. After 1990 a decrease in percentage is found. These results however don't show up in a simple linear regression. More refinement in the models used could improve the results.

For comparison, some results, found in literature, are summarised here. Remark that a good overview of studies on the changing storminess can be found in Smits *et al.* (2005). In Siegismund and Schrum (2001) data from the NCEP/NCAR reanalysis were used to analyse the wind speed and the wind direction over the period 1958-1997 over the entire North Sea. An increase of about 10 % was found in wind speed over that period. Also the measurements of the cubed wind speed in Utsira (Norway) shows an increasing trend over the period 1950-2000 (OSPAR Commission, 2000). These NCEP/NCAR data were also used by Weisse *et al.* (2005) to force a regional climate model for the North Atlantic Ocean. The results were analysed to look for trends in the occurrence of moderate and severe storms. They found important regional differences with opposing trends above and below 45°N. In the Southern North Sea, an increasing trend in the storminess was found for the period 1958 till 1990-1995. Since 1990-1995 a decrease in storminess occurs at the Southern North Sea. On the other hand, a recent study of Smits *et al.* (2005) analysed a set of high quality wind speed measurement in The Netherlands. They found a continuous decrease of the number of storms over The Netherlands from 1962 to 2002. They concluded that the inhomogeneities in the NCEP/NCAR analysis data were the main cause of the discrepancy between their results and the results of Siegismund and Schrum (2001) or Weisse *et al.* (2005). It is clear that further research is needed to come to a conclusive answer.

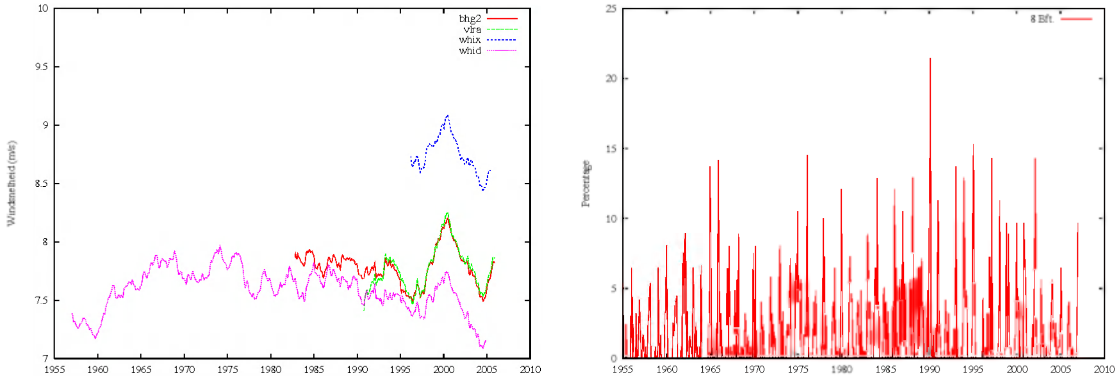

Figure 5: (a) Left: Long term trend of the measured wind speed at Brouwershavensche Gat 2 (bhg2), at Vlakte van de Raan (vlra) and at Westhinder (whix) and long term trend of the wind speed at Westhinder, extracted from the meteorological prediction of the DNMI

Concerning the wind direction, an increase in south-western winds is found over the last decades. This is visible in the larger increase in the winds towards the north, when analysing the long term trend of the wind components separately (Figure 6a). Also when looking the variation in the wind density function (Figure 6b), as defined in Siegismund and Schrum (2001), over the decades, an increase, in frequency or in intensity, of west-south-western winds is visible. This agrees with the results, obtained in Siegismund and Schrum (2001).

Further details on this trend analysis of waves, wind speed and wind direction can be found in Van den Eynde *et al.* (2008).

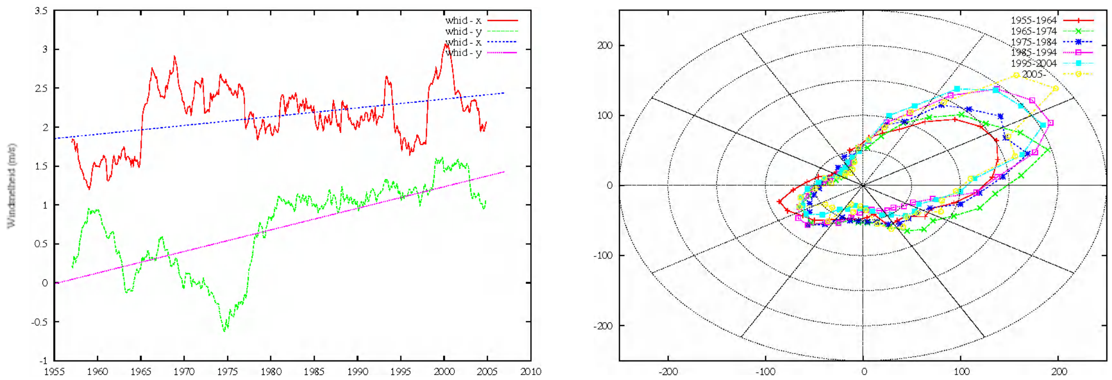

Figure 6: (a) Left: Long term trend of the wind speed components (x: wind to the east, y: wind to the north) and (b) Right: wind density function for different decades, from the wind at Westhinder, extracted from the meteorological prediction of the DNMI

3.2.3.3 Analysis of sea surface temperature

For the determination of the primary effects of climate change, the evolution of sea water temperature is also of importance. As shown in Ponsar *et al.* (2008), the sea water temperature is of great importance for the changes in the marine ecology. Also for the fisheries sector, the variations of sea water temperature can have large effects, *e.g.,* on the spatial distribution of the marine species. Since for the fisheries, not only the Belgian coastal waters are of importance, this analysis is performed for the entire North Sea.

The data which were used for the analysis were data from the World Ocean Database 2005 (WODB), which were received via the Belgian Marine Data Centre (BMDC). More then 127000 sea surface temperatures were obtained in an area from 4°W to 12.5°E and from 51°N to 61.5°N and over a period from 1971 to 2007. Since no data in the Channel and the Irish Sea were obtained, also some data from the British Oceanographic Data Centre (BODC) were requested. Almost 19000 measurements were obtained in a larger area.

The data were combined to make monthly mean time series for 36 boxes in the entire North Sea. The entire area considered extends from 12°W to 12°E and from 49°N to 61°N. Boxes were made with a resolution of 2° in latitude and 4° in longitude. One must remark that in only 15 boxes, sufficient data were available to make monthly mean time series, for which in at least 50 % of the months, measured data were available. Using the BODC data, time series for 5 more boxes were prepared, for which in at least 25 % of the months, some measurements were available. As discussed above, the missing data were interpolated using the long term trend and the seasonal cycle (Visser *et al*., 1996). It is clear however, that the data from the BODC are subject to large uncertainties.

In the long term trend in the different boxes a clear increasing trend can be observed (Figure 7a for the data from WODB). Furthermore, also here a natural decadal variability is apparent, with a period of about 7 to 8 years. This agrees with the variability in the NAO, as reported in Sündermann *et al.* (1996). The slopes of the linear regression for the same boxes are presented in Figure 7b. The values vary between 0.023 °C yr^{-1} in the Skaggerak and in the North of the North Sea to 0.053 °C yr^{-1} in the central North Sea and the southern North Sea. These values roughly agree with the values found in literature (*e.g.,* Ponsar *et al.* 2007). Further details on this trend analysis of sea water temperature can be found in Van den Eynde *et al.* (2008).

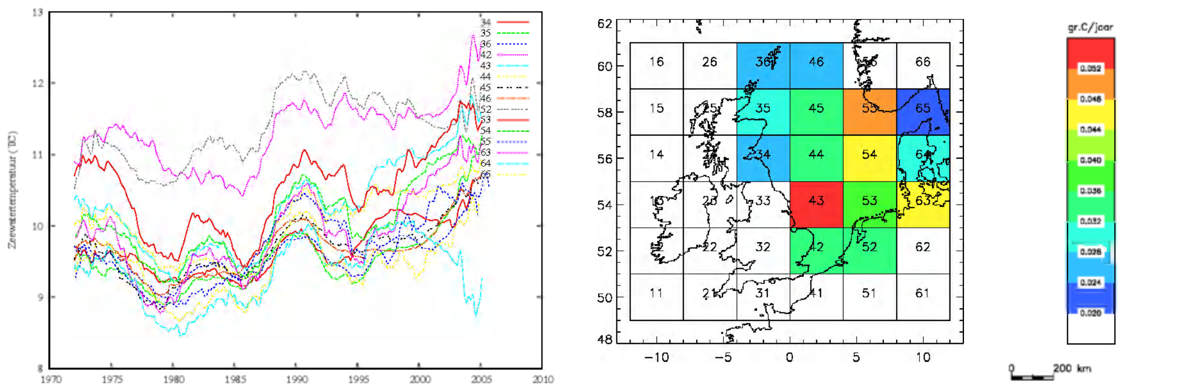

Figure 7: (a) Left: Long term trend for the sea surface temperature in different boxes in the North Sea (b) Right: Trend, calculated by a linear regression of the sea surface temperature in different boxes in the North Sea.

3.2.4 Numerical models

A last method to evaluate the primary impact of global climate changes is the use of numerical models. Different numerical models are available: hydrodynamic models, wave models and sediment transport models. These models will be used to simulate the current situation and to assess, *e.g.,* the maximal bottom stress or amount of mud deposited at the bottom. The variations in these parameters, under the influence of the climate changes as described in the scenarios, *e.g.,* sea level rise or increased wind speed, can be assessed. As an example, in Figure 8, the magnitude of the maximum tidal currents in the Belgian coastal waters are presented for the current situation (left), together with the changes to the magnitude of the maximum tidal currents in the Belgian coastal waters for the Worst Case Scenario (scenario 5), defined above (right), *i.e.*, for a sea level rise of 2 m and a wind speed increase with 8 %. While in the mouth of the Westerschelde, the maximum bottom stress decreases by around 10 %, in the region between Nieuwpoort and Zeebrugge, the maximum bottom stress increases. These changes can have important effects on the amount of mud that could be deposited on the bottom or on the type of biota that could be found.

In the framework of the project, the SWAN wave model has been implemented for the BCP. This wave model and different sediment transport models will be used to evaluate the changes in different hydrodynamic and morphodynamic parameters for the different scenarios defined.

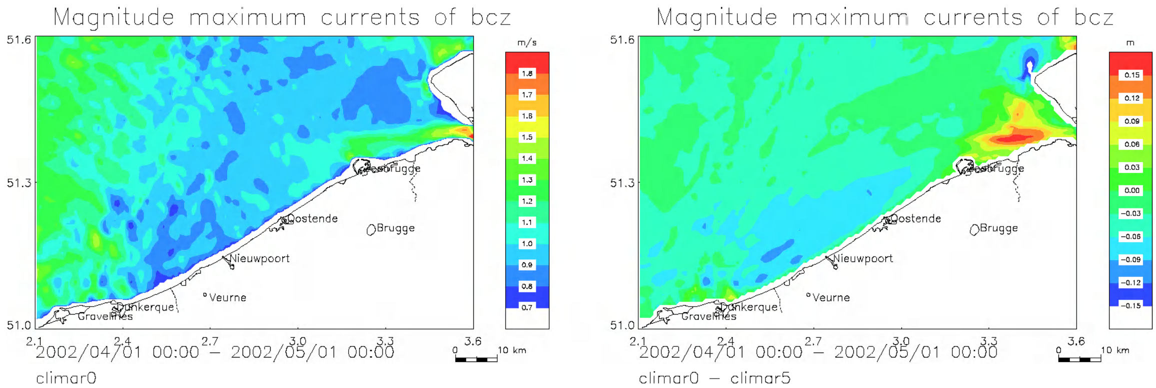

Figure 8: (a) Left: Maximum currents on the BCP as simulated with the MU-BCZ model for the present situation (b) Right: Changes to the maximum tidal currents for the Worst Case scenario.

3.3 Climate change scenarios

As mentioned, a way of dealing with the uncertainties of possible impacts is to draw a series of climate change scenarios. In the framework of the CLIMAR project, three scenarios were presented. These scenarios are based on similar scenarios which were set up in the neighbouring countries, like The Netherlands, the United Kingdom and Germany.

Five scenarios were drawn for 2040 (mid-term) and 2100 (long-term): two moderate (M, M+) scenarios, two warm scenarios (W, W+) and a worst case scenario (W). In the M and W scenarios, there is no significant change in air circulation patterns, and the precipitation increases both in summer and in winter with about 3 % per °C of air temperature increase. In the M+ and W+ scenarios, there are significant changes in air circulation patterns and the precipitation increases more in winter (about 7% per °C of air temperature increase) and decreases in summer (about 10% per °C of air temperature). This decrease in summer precipitation is mainly attributed to the decrease in the number of rainy days. A strong change in air circulation induces warmer and moister winter seasons and increases the likelihood of dry and warm summer time situations.

In Table 1 the five scenarios are presented for 2040 and in Table 2 for 2100. The scenario for 2100 is simply a linear interpolation of the values for 2040. Note that the sea level rise in the last improbable 'worst case' scenario, accounts for some unexpected but possible effects, such as the massive melting of ice sheets and the stopping of the Thermohaline Ocean Circulation. This last scenario was proposed by Brooks *et al.* (2006).

Table 1: Climate change scenarios 2040

	M	M+	W	W+	Worst
Air temperature	+ 1° C	+ 1° C	+ 2° C	+ 2° C	+ 2° C
Change air circulation	No	Yes	No	Yes	Yes
Winter precipitation	+ 4 %	+ 7 %	+ 8 %	+ 14 %	+ 14 %
Wind velocity	0 %	+ 2%	- 1 %	+ 4 %	+ 4 %
Summer precipitation	+ 3 %	- 10 %	+ 6 %	- 20 %	- 20 %
Sea water temperature	+ 1.2 °C	+ 1.2 °C	+ 1.7 °C	+ 1.7 °C	+ 1.7 °C
Mean sea level	+ 30 cm	+ 30 cm	+ 40 cm	+ 40 cm	+ 100 cm

Table 2: Climate change scenarios 2100

	M	M+	W	W+	Worst
Air temperature	+ 2° C	+ 2° C	+ 4° C	+ 4° C	+ 4° C
Change air circulation	No	Yes	No	Yes	Yes
Winter precipitation	+ 8 %	+ 14 %	+ 16 %	+ 28 %	+ 28 %
Wind velocity	0 %	+ 4 %	- 2 %	+ 8 %	+ 8 %
Summer precipitation	+ 6 %	- 20 %	+ 12 %	- 40 %	- 40 %
Sea water temperature	+ 2.5 °C	+ 2.5 °C	+ 3.5 °C	+ 3.5 °C	+ 3.5 °C
Mean sea level	+ 60 cm	+ 60 cm	+ 93 cm	+ 93 cm	+ 200 cm

4 Secondary impacts

4.1 Deduction of secondary impacts both on the marine ecosystem as well as on other socio-economic activities – Identification

4.1.1 Regional

A literature study has been conducted to identify all secondary impacts taking place on a regional scale (Belgian Part of the North Sea), classified according to their ecological, social and economical nature.

At first a general terminology has been worked out, resulting in different effect categories. These effect categories group a range of effects (Table 3). An “effect” gives a more detailed description of the climate change impact defined under the “effect category”. While the “effect categories” are common for all sectors, the “effects” can be sector-specific. In this way impacts can be compared over sectors and allows for extrapolation towards the regional level (bottom-up).

The final list of effect categories considered in the CLIMAR project is given in Table 3. A detailed description can be found in Volckaert *et al.* (2008).

Table 3: Considered effect categories of CLIMAR

Effect categories	*Effect (definition + example)*
Ecological effect categories (mainly direct effects)	
Water quality	Related to physico-chemical aspects such as oil pollution, turbidity, salinity
Habitat quality	Leading to degradation (of improvement of coastal/ marine habitat (*e.g.*, coastal litter on beach)
Habitat change	Change/loss of natural habitat such as loss of fishery grounds, nature areas or change due to offshore structures
Ecosystem productivity	Change in the timing, abundance or composition of primary producers
Geographical shift	Moving/replacement of species (composition) due to climate change (temperature increase, etc.)
Establishment of non-indigenous species	Introduction and survival of species not naturally occurring in West-Europe
Ecosystem component interactions	Decoupling of phenological relationships with impact on recruitment, food availability, etc.
Biodiversity	Change in biodiversity as a result of one or more of the described effect categories
Other biological events	Other biological effects such as harmful blooms
Economical effect categories (mainly indirect effects)	
Change in production	Decrease in production due to destruction of certain facilities, damage to boats, difficulties/restrictions for executing job (# sea days), ecological consequences, etc. Increase in production due to better ecological consequences, etc.
Production value	Expressed in terms of the “price of the product” and determined by the availability of the product and the changes in cost (~ exploitation, damage)

Effect categories	*Effect (definition + example)*
Exploitation costs	The costs needed to exploit a unit (quantity) of the considered product (~activity, transport)
Damage costs	Damage as a function of maintenance and insurance costs *e.g.*, damage to private or public properties (buildings, equipment, stocks, machinery), damage to transport infrastructure, damage to service networks (gas, water, electricity, telecommunication, coastal infrastructure)
New opportunities	Such as new activities or new "climate proof" technological initiatives
Economic result	Expressed as profit (positive) or loss (negative) and calculated by decreasing the total turnover (= revenues) with the total costs (wages, rent, fuel, raw materials, interest on loans and depreciation)
Social effect categories (mainly indirect effects)	
Attractiveness coastal & marine area	Overall term used to describe the degree in which the society attaches importance to the coast (recreational value, leisure opportunities)
Employment	Direct loss/ increase of jobs
Human settlement	Availability and occupation of coastal housing units
Safety	Risk of accidents, *e.g.,* flooding of houses (human settlement), flooding of business property, accidents at sea (transport), accidents during work activity (exploitation)
Accessibility	Accessibility of the coast expressed in time needed to reach the coast and the status of the transport infrastructure (public and road) Accessibility of the marine ports expressed in time needed to enter the port
Health	Health effects considered are mortality in function of extreme temperatures (heat, cold); stress related problems; diseases due to bad water & seafood quality
Cultural value	Coastal cultural heritage and values
Welfare (individual and family life)	Indirect effects as a result of social changes (changes in employment, human settlement, safety, health, etc.). It deals with the aspect of "life quality" (~purchasing power; ~family relationships).

4.1.2 Sectoral

4.1.2.1 General

Climate change will affect sectors in a different way, but also within a sector differences can be observed depending on the activity considered. The sectors selected for the CLIMAR study are: coastal flooding, fishery and tourism. The different sectors have been divided into several subsectors (only when relevant). For example for the sector "Tourism" following subsectors have been identified: beach tourism, water tourism, ecotourism, gastronomic tourism, cultural tourism, health tourism, holiday and business.

As a base for the identification of the secondary impacts, the results were taken from the primary impact assessment. At first, a process diagram has been worked out per marine sector linking these primary effects with identified secondary impacts (subdivided into ecological, social and economical effects).

Secondary impacts will further be worked out in more detail per subsector.

- What are the climate impacts on the sector? The relevant secondary effects will be described per effect category (ecological, social and economical). While most climate change effects will be negative, some can have positive consequences for the subsector
  (+/-). Finally, it will be important to identify whether there are critical thresholds in the system that may be exceeded, causing significant impacts. For instance, persistent high temperatures over a period of a few days can lead to specific health effects.
- Could there be indirect climate impacts too? The identified effects can be the direct result of a primary effect (direct effect), but they can also arise from a secondary effect (indirect effect). These relationships are also identified within this step.
- Are climate impacts important to the sector? What are the priority climate risks? Not all climate impacts will be as important to the sector. As we need to focus on actions to manage priority climate risks, we should identify the most important risks for the subsector (4= very high; 3=high; 2=medium; 1=low risk). To identify them following aspects should be considered:
  - Already existing high risks;
  - Risks that will increase more rapidly due to climate change, especially if they cross some critical threshold;
  - Risks where it will take some time to plan and implement adaptation responses;
  - Risks in areas very sensitive to changes in the climate;
  - If an “early-mover” advantage is wanted on a climate change business opportunity.
- Will climate impacts be more or less important than the other risks the sector faces? In developing adaptation strategies, it will be necessary to assess the relative sensitivity of the sector to other non-climate risks. It could be that other external factors (*e.g.,* demographic change, international market) are much more determining the future evolutions of the sector, than that climate change does. So alongside climate change scenarios, socio-economic scenarios have been developed to take these external non-climate changes into account.

All information has been summarised per sector in an impact table. A distinction was made between ecological, economical and social impacts. The format of such a table is given for (some of) the ecological effects of the tourist sector (Table 4). At this moment, the impact tables for fisheries, coastal flooding and tourism have been finalised.

Table 4: Format of impact table "Identification step" (Extract of the ecological effects of the tourist sector)

Ecological effects									
Sector		***Identification***							***Priority***
							PE: Primary effect (incl. direct links)	***SE: Secondary effect***	
Sector	*Subsector*	*Effect category*		*Ecological effect*	*+/-*	*Direct?*	*Related to (effect category)*	*Induced by (effect)*	*Priority score*
Tourism	Beach tourism	Water quality	T-WQ1	Decrease of bathing water quality (measured by #	-	Yes	(PE) biogeochemical cycle, t°		2
		Water quality	T-WQ2	Change in colour of sea water (turbidity)	-	Yes	(PE) Biogeochemical cycle		1
		Habitat quality	T-HQ1	Amount of marine and coastal litter	-	Yes/no	(PE) Increased storminess	(SE) Increased tourism	2
		Etc.							
	Ecotourism	Habitat change	T-HC2	Loss of dune area, protected areas	-	Yes	(PE): coastal erosion, sea level rise		3
		Geographical shift	T-GS2	Increase of sea mammals (harbour porpoise, common seal)	+	Yes	(PE) t°		3
Etc.									

4.1.2.2 Case study of coastal flooding

As mentioned above, the most important primary effects on coastal flood risks are sea level rise and increased storminess (more storms, higher storm surges and increase of wave height).

In a first step the secondary impacts on coastal flooding are identified and described in 3 different effect categories: ecological, economic and social effects. This step is based on literature and expert knowledge. The identified ecological impacts of climate change related to coastal flooding are changes in water quality due to altering circulation patterns around offshore defence structures and near foreshore nourishments or due to changing currents around sand extraction sites. Turbidity of the water around extraction areas will also affect water quality. Furthermore, freshwater in dunes will turn brackish due to salt water intrusion as a consequence of sea level rise. Other ecological effects are habitat change and changes in biodiversity. Natural ecosystems are interrupted due to the construction of defence structures and due to beach and foreshore nourishments. North Sea sand extraction also threatens marine habitats. Furthermore, increased coastal erosion results in loss of beach area but beach nourishments can compensate for this loss. The construction of offshore defence structures can also affect beach erosion or accretion. On the other hand, defence structures are good environments for colonisation by marine fauna and flora. Finally, flooding events can lead to loss of specific habitats whereas under managed retreat habitat diversity can increase.

Secondary economical effects of climate change can be change in production when offshore economic infrastructure gets damaged during extreme storms, change in production value due to increased costs for protection against sea level rise, higher damage and insurance costs due to flooding (damages to buildings, industry, agriculture, transport infrastructure, service networks, coastal defence structures, vehicles, …). Damages to industrial and agricultural properties will subsequently lead to temporary or permanent decrease in production. Indirectly, this can result in economic losses at supplier and customer companies. Climate change can also lead to new opportunities: economic activities such as aquaculture or land winning can be coupled to alternative offshore defence measures. Also flooded areas, beach nourishments and alternative offshore defence structures can be given a destination as natural and/or recreational draw.

Secondary impacts of climate change on the social system are related to safety (occurrence of flooding casualties and higher flooding risks), accessibility (difficult navigation to and through ports due to the construction of defence structures and obstruction due to damages to transport infrastructure), employment (temporary or permanent loss of jobs in flooded areas and increase in jobs for the construction of new defence structures), attractiveness (loss of space for leisure activities due to beach erosion or increase in beach area due to nourishments, disturbed beach view due to defence structures on the coastline or offshore and more natural and/or recreational area in account of managed retreat) and welfare (flooding damages and casualties and temporary or permanent loss of jobs in flooded areas).

4.1.2.3 Case study fisheries

Climate change can impact the Belgian sea fisheries indirect via the fish stocks, the natural resource the fisheries depends upon, and direct via the (weather) conditions in which the vessels have to operate.

In dialogue with the other project partners different effect categories — split into 3 main groups (ecological, economical and social effect categories) — were identified and are used where appropriate by all partners to describe the secondary impacts on each marine activity and allowing easy integration of the findings / adaptation strategy for each considered sector.

More than 50 secondary effects were identified and listed in an overview table. Each effect was given a unique code, which allows showing the relation between the effect and the primary effect or other secondary effect it is caused by.

The secondary effects identified under the ecological effect categories are strongly linked and reflect the complexity of the ecosystem. The literature study, dealing with the impacts of climate change on the ecological parameters (see 3.2.2) already indicates that all trophic levels of the food web are affected by climate change. The status of the fish stock, which forms a component of the ecosystem considered, is therefore associated with the whole ecosystem and the changes it is undergoing due to climate change. Many studies consider temperature as the most important factor in relation to fish stocks and analyses are performed using temperature as main indicator (Beaugrand, 2004; Brander, 2006; 2007; Cook and Heath, 2005; deYoung *et al*., 2008; Frid *et al*., 2008; ICES, 2007; 2008a; 2008b; Klyashtorin, 2001; Perry *et al.*, 2005; Rijnsdorp *et al.*, 2008; Stiansen *et al*., 2005). Thus, the status of the (potential) commercial fish stocks and the effect of (future) water temperature rise will be considered for quantification.

The effect that several other primary impacts like acidification, turbidity, etc. can have on fish stocks was described but not further quantified.

In order to identify the secondary effects classified under the economical effect categories the fish stocks, *e.g.,* potential catch, are considered as production. Hence economical effects are closely linked with the status of the different fish stocks. Primary effects like storminess and changes in prevailing winds can influence the operational functioning of the fleet and reduce the income of the ship owners.

Secondary effects identified under social effect categories comprise mainly safety for crew and vessel, welfare and employment.

4.1.2.4 Case study tourism

For the case-study of tourism the most important primary effects are temperature and circulation patterns (precipitation, wind and currents) both determining the climatic conditions at the coast and sea level rise increasing the risks of natural hazards such as flooding and coastal erosion.

Other important secondary impacts besides the attractiveness of the coast in terms of pleasant climatic conditions and the loss of dune/beach area due to flooding or erosion, are the occurrence of sea mammals (geographical shift) as the food availability and temperature changes, increased damage costs to marinas due to sea level rise, changed accessibility of the coast due to damage infrastructure, the creation of new commercial activities (in water tourism, eco tourism) and an overall change in the turnover of the tourism sector. As can be seen climate change can influence the sector both in a negative and positive way.

A complete list of the identified secondary effects can be found in the subdocument of the Sector Tourism (Volckaert *et al.*, 2009).

4.2 Deduction of secondary impacts both on the marine ecosystem as well as on other socio-economic activities – Quantification

4.2.1 Quantitative description of the marine sectors

A quantitative description (spatial, intensity, social importance (valuation), economical importance (jobs, profit, etc.) has been executed for fisheries, coastal flooding, tourism based on available literature, data bases and personal communications with the sector. The results have been described in a separate subdocument per sector.

4.2.1.1 Case study coastal flooding

The Belgian coastal plain is a very intensively used zone. Directly on the shoreline more then 50 % of the area is occupied by industry or housing, while the low-lying polders further inland are mainly used for agricultural purposes. In Van der Biest *et al.* (2009a) a quantitative description is given of all the types of land use and infrastructure threatened by coastal flooding: sea defence structures, nature, buildings, industry and business, agriculture and service and transport networks.

The quantification of the main economical and social secondary effects is based on a numerical model developed by Flanders Hydraulics Research and University of Ghent: the LATIS software version 1.2 for damage and victim calculations. To each land cover type and object in the Belgian coastal plain a maximal damage value in € is attributed (Table 5). The victim calculation is based on the population number per municipality (National Instituut voor Statistiek, 2007; Wikipedia, 2008).

Table 5: Maximal damage values per land cover type or object (translated and adapted from Vanneuville *et al.*, 2006)

Land cover or	Damage
Houses	Maximal damage in function of building density; direct damage in function of average sales value per region + indirect damage as cleaning up costs: 15% of direct damage when initially limited damage, 1% when total loss of house and moveables. Separate calculation for salt water.
Moveables	Maximal damage 50% of the maximal damage to house; also indirect damage (see 'Houses')
Industry	Two damage assessment methods: - based on surface: € 100/m²; indirect damage due to production loss and cleaning up costs 35% of direct damage when total loss and 45% when initially limited damage - based on number of employees: maximal damage in function of density of employees in industrial area (per municipality); €180.000 per employee; indirect damage due to production loss and cleaning up costs 35% of direct damage when total loss and 45% when initially limited damage
Infrastructure	€ 100/m² (buildings and installations not included in other categories, *e.g.*, sheds, railway stations, platforms, buildings at recreational areas, cemeteries …)
Airports	Airport of Oostende considered separately; smaller airports: € 100/m² for airport I (buildings, runway), € 0/m² for airport II (area without buildings or infrastructure)
Recreational area	€ 0,03/m² (cleaning and repair costs: benches, information signs, … ; not included buildings). Separate calculation for salt water.
Arable land	Value in function of crops and dependent on agricultural area and watershed; Flemish average ± € 0,50/m²; indirect damage: loss soil fertility and cleaning up costs 10% of direct damage. Separate calculation for salt water.
Pasture land	€ 0,08/m², indirect damage (cattle can't use land during and right after flooding, hay land covered with mud) 10% of direct damage
Vehicles	€ 4.500 per vehicle
Water, nature, forests	€ 0/m²

Roads	Value depends on type of road; varying between € 300/m and € 7.500/m
Railways	Value depends on type of railway; varying between € 500/m and € 7.500/m
Water supply	Value depends on expert opinion. Confidential
Amusement parks	Value depends on expert opinion. Confidential
Convents, abbeys, hospitals, town halls and schools	€ 1.150/m²
Churches	€ 1.150/m², fixed area of 400m²
Fire stations, police	€ 1.600/m²
Museums	€ 1.600/m², fixed area of 1.800m²; not included value of the collection
Historical mills	€ 687.500 per piece
Castles	€ 10.000.000 per piece
Rest homes	€ 12.500.000 per piece
Train stations	Differentiation between: - Large stations: value depends on expert opinion. Confidential - Medium-sized stations: € 295.000 per station - Small stations: € 30.000 per station
Power stations	€ 4.500.000.000 per station
Wind turbines	€ 712.000 per turbine
Transmitting	€ 60.000 per installation
Underground parking	€ 7.500.000 per garage
Subway stations	€ 5.000.000 per station
Gas stations	€ 900.000 per station
Shopping malls	€ 50.000.000 per mall

4.2.1.2 Case study fisheries

The Belgian fisheries sector is currently going through a crisis and many ship owners are on the verge of bankruptcy. Therefore ILVO-Fisheries felt that, in order to get a better understanding of the impacts induced by climate change and as input for the development of adaptation strategies, it was necessary to focus on the present situation of the Belgian fisheries sector and its most important drivers. A document giving a detailed description of the fisheries sector/fleet was drafted and addressed the current situation and the external factors which (may) affect the future of the fisheries sector and make it more vulnerable to climate change impacts (Vanderperren and Polet, 2009). Some relevant findings:

4.2.1.2.1 Fleet composition

The number of fishing vessels dropped from 457 vessels in 1950 to only 102 vessels end 2007, making the Belgian fleet the smallest in Europe. The fleet halved between 1960 and 1980, decreased further to become rather stable between 2000 and 2005. Since 2006 the number of vessels is decreasing again. Total tonnage and total engine power of the fleet did not decrease accordingly over the last decades, indicating that the vessels became larger, with a higher individual capacity. In 1991 the average tonnage and engine power amounted to almost and 25000 GT and 80000 kW. Since 1992 these averages decreased systematically to the current level. The Belgian Fisheries administration divides the fleet into sub fleets based on the engine power of the vessels (Tessens and Velghe, 2007).

4.2.1.2.2 Fishing method

The Belgian fishing fleet consists of approximately 93% beam trawlers, mainly targeting sole and plaice. Beam trawls are also used to fish for shrimps and Norway lobster. Beam trawling is a highly mixed fishery and by consequence vulnerable to management measures protecting single fish stocks like cod or plaice. Beam trawling as a fishing method couples a number of problems such as high fuel and material consumption, heavy seafloor impact and low species and size selectivity. Otter trawls and passive fishing methods are used to a lesser extend.

4.2.1.2.3 Fishing grounds / landings

The Belgian fleet is active in several ICES-areas, the most important are: Central North Sea (IVb), Southern North Sea (IVc), Irish Sea (VIIa), Eastern Channel (VIId), Bristol Channel (VIIf) and South East of Ireland (VIIh,j,k) (Tessens and Velghe, 2008).

The annual landings of Belgian vessels decreased from roughly 35 thousand ton in the late eighties-early nineties, to less then 22000 ton nowadays. Compared with 2006 the landings for 2007 increased slightly. As most Belgian vessels fish with beam trawls their landings consist mainly of demersal species. The top 10 of landed species in 2007 indicates that plaice (5501 ton) and sole (3676 ton) are the most important species, followed by ray (1811 ton), squid (1607 ton) and cod (1074 ton) (Tessens and Velghe, 2008).

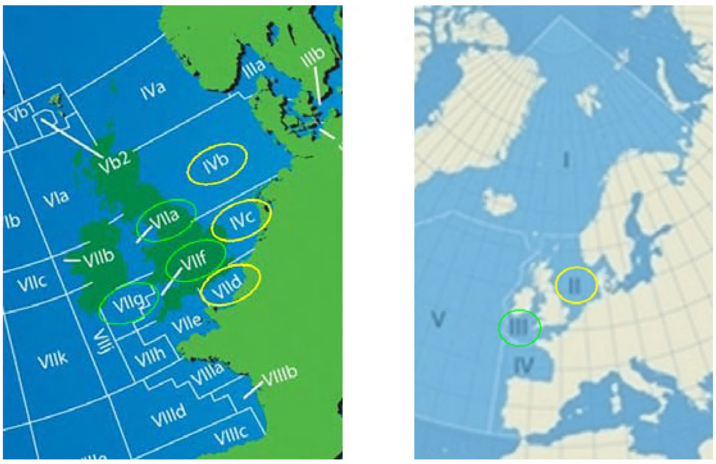

Figure 9: Fishing grounds (ICES and OSPAR)

4.2.1.2.4 Economic / social

The gross added value of fisheries on production level is very low compared with the gross domestic product, namely 0.04 %; compared with the total value of agro- and horticulture its 1.9 %. However, Belgium has a very small coast line and the sea fisheries sector is very important on a regional level (Tessens and Velghe, 2007; Demeyere, 2003). Fisheries has its impact on the socio-economic structure, like specific trades correlated with fisheries, distribution chain, fish processing companies, fish traders, catering industry and coastal tourism.

4.2.1.2.5 Strengths and weaknesses

In agreement with experts working at ILVO-fisheries on different subjects related to fisheries a analysis of the Belgian fisheries sector was performed indicating that the following characteristics are strengths or creating opportunities: the efficiency of the beam trawl, beam trawling being mixed fisheries (high catch capacity), the fleets flexibility with regard to fishing ground, expertise of the ship owners/ skippers /crew, the fact that shipping companies are often family business, an improved communication between the different stakeholders, the availability of a framework for financial support from the government, …

Some of these strengths could be considered as weaknesses or threats as well. The following weaknesses or threats were identified: high fuel costs, high material costs, high investment costs, one-sided fleet structure, ecological impact and limited selectivity of the beam trawl, no knowledge on other fishing methods, high age of vessels, closed areas, shortcoming of the current regulation/quota, public image of the sector, import of cheap fish, … (ILVO-Fisheries, 2008).

4.2.1.2.6 External factors

(Potential) external factors influencing the fishing industry now and/or in the future are identified: fuel prices, fish prices and national and international regulations/policy (Common Fisheries Policy, precautionary approach – Maximum Sustainable Yield, Total Allowable Catch, Limitation of fishing effort, technical measures, recovery plans, ecosystem approach, ban on discards, European Fisheries Fund and National Strategic Plan).

4.2.2 Socio-economic scenarios

The development of the socio-economic scenarios is based on the scenarios of the Milieurapport Vlaanderen (MIRA) (Vlaamse Milieu Maatschappij, 2009) and scenarios developed in neighbouring countries (*e.g.,* the Netherlands).

4.2.3 Quantifying the secondary impacts

4.2.3.1 General

For the quantification of the secondary impacts an indicator approach (Figure 1) has been chosen. In this approach a distinction has been made between: 1) Elements at risk indicators and 2) Vulnerability indicators. The selection of indicators has in the first step been based on available monitoring programs (SAIL, WFD, OSPAR, etc.). Besides, new indicators have been developed within the scope of CLIMAR.

Indicators have been worked out for the most significant climate risks and described in an Indicator Fact Sheet (IFS) addressing following issues: definition, policy relevance, methodological description, data availability and organisations involved in the development of the indicator. This task has been finalised for coastal flooding, fisheries, and tourism.

The quantification of the secondary effects (SE) per sector will be the result of three steps (see Figure 2):

- Current status: The quantification of the selected indicators based on the most recent available data. Roughly spoken this will relate to the “Elements at risk” factor of the SE within the described indicator approach;
- Climate change impact: The relation of the primary effects (linked with the climate change scenarios) and the secondary effects (selected indicators) will be described. As a result the main impact will be quantified for both climate change scenarios. To be able to quantify this climate change impact for a specific secondary effect, it will be necessary to consider the “Vulnerability” aspect described in the indicator approach;
- Overall impact: As mentioned before next to the climate change scenarios, socio-economic scenarios (both mid and long-term) should be considered in order to quantify the overall impact. Socio-economic (external) factors can both influence the “elements at risk” (*e.g.,* population growth will lead to more people at risk) and the vulnerability to a certain climate risk (*e.g.,* increased fuel price will worsen economical impact on fisheries).

Based on the results of the climate change scenarios, and taking into account the socio-economic scenarios a start has been given to quantify the effects according to the methodology presented in Figure 2.

4.2.3.2 Case study of coastal flooding

Following indicators have been selected to be quantified as indicators for the risks of climate change related to coastal flooding:

Table 6: Selected main risks and their indicators for the case-study coastal flooding

Effect category	Effect	Direct / Indirect	Related to	Indicator
Ecological - Habitat change	Coastal erosion (loss of beach and dune area)	Direct	State of sea defence, beach tourism and ecotourism	% of coastline that is eroding per municipality / year
Economical – Damage costs	Damages due to flooding	Direct	Flooding, coastal erosion	Damage model
Social – Safety	Casualties	Direct	Sea level rise, increased storminess	Casualties model

Within the scope of the CLIMAR project, these indicators are quantified by means of different numerical models. Due to the time-consuming risk calculations only two climate change scenarios are considered within the case-study coastal flooding, besides the current status: the M+ scenario, representing the minimum scenario of climate change, and the worst case scenario (WCS). However, the quantification results of the effects in the other scenarios are expected not to differ substantially from the considered scenarios.

4.2.3.2.1 Coastal erosion

The indicator "coastal erosion" is described as the percentage of the total beach and dune foot area that is lost in the different scenarios of climate change, given per municipality. The total loss of beach area due to sea level rise can be estimated by calculating the area between low-water level (+1.39 m TAW) and dune foot or dike for each climate scenario by 2100.

The table below gives an overview per municipality of the total beach area expected to be lost due to sea level rise. An average loss of 17 % beach area can be expected for the entire coastline in the M+ climate scenario by 2100, while in the worst case climate scenario an average loss of almost 50 % of the Belgian beach area is calculated.

Table 7 - Loss of beach area due to sea level rise

Scenario	Present (2006)	M+ (2100)	WCS (2100)	M+ (2100)	WCS (2100)
Municipality	**Available beach area (km²)**			**% loss beach area**	
De Panne	1.53	1.25	0.75	19	51
Koksijde	2.70	2.20	1.39	18	49
Nieuwpoort	1.06	0.89	0.53	17	50
Middelkerke	1.64	1.38	0.73	16	55
Oostende	1.55	1.25	0.62	19	60
Bredene	0.84	0.70	0.00	17	47
De Haan	2.64	2.15	1.37	19	48
Blankenberge	0.82	0.68	0.43	17	47
Zeebrugge	1.02	0.89	0.66	13	35
Knokke-Heist	2.69	2.37	1.62	12	40

4.2.3.2.2 Damage costs and victims

The damage costs and number of victims due to flooding are quantified by means of a methodology based on the risk assessment methodology developed by Flanders Hydraulics in the scope of the European project SAFECOAST (Verwaest *et al.*, 2008a).

Each scenario of climate change is statistically translated into a worst credible storm event with an associated return period of 1/17000 years (Verwaest *et al.*, 2008b). A storm with return period 1/17000 yr and present-day sea level and wave climate corresponds to a storm surge level of +8 m TAW in Oostende. For comparison, the most severe storm of the past 100 years (February 1953) reached a storm surge level of +6.66 m TAW at Oostende. In the M+ scenario (+0.6 m sea level rise and increase in wind speed of +4 %), the extreme storm corresponds to a storm surge level of +8.8 m TAW in Oostende. Given the worst case scenario of climate change by 2100 (+2 m mean sea level rise and increase in wind speed of +8 %), a storm with return period 1/17000 years corresponds to a storm surge level of +10.4 m TAW in Oostende.

The first step in the flood risk methodology carried out in the scope of CLIMAR is the estimation of beach and dune erosion during an extreme storm event. For this purpose the software package DUROSTA (Delft Hydraulics) is used. The model is one dimensional and requires cross-shore profiles as input. The Belgian coast is divided into 256 sections of about 300 m wide. For every section at least one cross-shore profile is chosen, that is the weakest point of the section. Often this is near streets or dune passages. In total, the calculations are carried out for 380 profiles. The profiles are drawn from -5 m TAW in the sea to +5 m TAW behind the range of dunes, representing the natural sea defence. The structural resistance of hard defence structures (sea dikes and dune foot strengthening, as well as the buildings on top of the sea defences) are not taken into account, because in general such structures are only able to temporary withstand a super storm. Reference is made to the results of a

study in which this structural resistance of hard defence structures is quantified: Vanpoucke *et al.* (2008). This approach allows us to identify the weakest points in the sea defence along the Belgian coastline. The input wave conditions at the start of the profile (-5 m depth contour) are estimated with the two dimensional program SWAN2D. This program simulates the transformation of waves from deep water to near shore. For the current situation, deep water conditions come from extreme value statistics on the measurements of the survey buoy at Westhinder (Verwaest *et al.*, 2008). For the M+ and the WCS scenarios by 2100, deep water conditions and water level for an extreme storm are estimated based on the correlation between wave characteristics (wave height and period) and wind speed. In the M+ scenario with a sea level rise of +0.6 m and an increase in wind speed of 4 % a storm surge level of +8.8 m TAW in Oostende can be expected. Given the WCS scenario with a sea level rise of +2 m and an increase in wind speed with 8 %, a storm surge level of +10.4 m TAW in Oostende is expected.

The results of the erosion calculations for each cross-shore profile are used to calculate the remaining dune volume above the water level at any moment of the storm. This volume is compared to a critical threshold volume which is a function of wave height and wave period (Figure 10). When the remaining volume is less then the threshold volume, a breach is expected to occur.

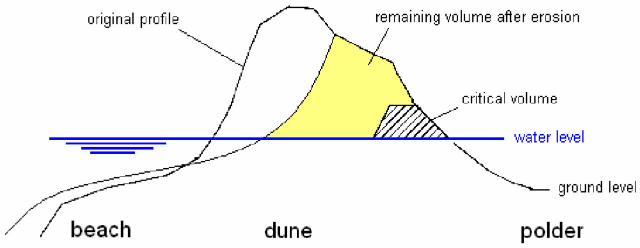

Figure 10: Evaluation of remaining volume compared to critical volume

Next, breach growth and hydraulic flooding of the coastal plain are simulated by means of the software package MikeFlood (Danish Hydraulics Institute). The calculations are carried out on an altimetry grid of 100 m by 100 m. For each pixel the model estimates depth, current velocity and rise velocity of the water flooding the coastal plain.

These resulting grids are then used to calculate the total amount of damage costs [€] as well as the number of deadly victims [#] in the coastal plain. The monetary damage costs are a function of the landuse, water depth and current velocity. The number of deadly victims depends on water depth, current velocity, rise velocity, the number of inhabitants and the possibility of evacuation (however, no evacuation is taken into account considering the limited preparedness). More detailed information on the risk calculations can be found in Van der Biest *et al.* (2009a).

Current status

Along the Belgian coastline 3 weak points in the natural sea defence are identified: Mariakerke, the centre of Oostende and Wenduine. The critical threshold volume is reached generally right before the peak of the storm or maximum 1 hour before the peak, except for the centre of Oostende where the breach starts to develop more or less 1 hour after the peak of the storm. In the current situation, an extreme storm reveals to cause breaches in the natural sea defence only near cities. At these locations the natural sea wall (dunes) is lowered for the construction of buildings and roads. The flood zone remains confined to nearshore and low-lying areas (Figure 11). The area with highest flood damage costs is found at Oostende. The risks are higher due to the concentration of buildings and population in the city. The total damage cost is estimated at 4.1*10^{8} €, while the number of victims is estimated around 10.

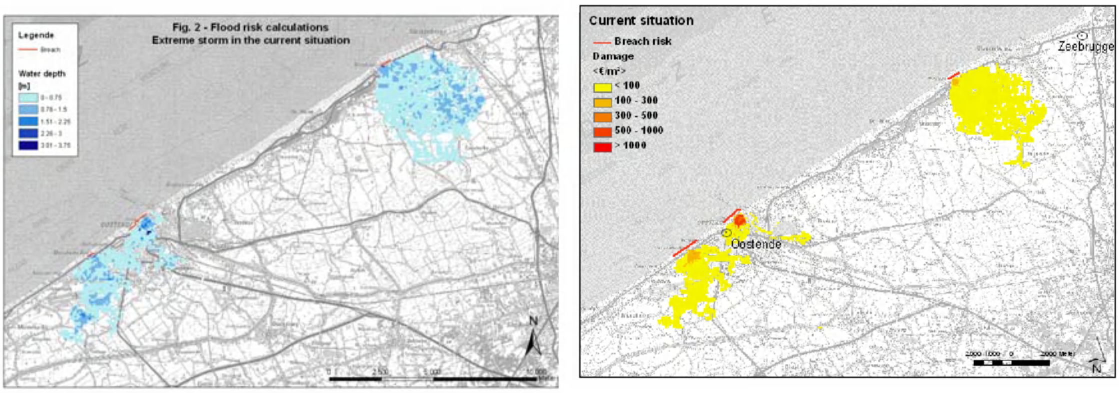

Figure 11: Results of the flood risk calculations for an extreme storm in the present situation. Left: water depth, right: total damage.

M+ scenario 2100

In the M+ scenario by 2100 breaches are expected to occur mainly off seaside resorts but also at dune passages. The greatest risk of flooding and damages to infrastructure arise near the sea defence, due to the force of the inrushing sea water. The total damage cost is estimated at 3.35*10^{9} €, while the number of victims is estimated around 260.

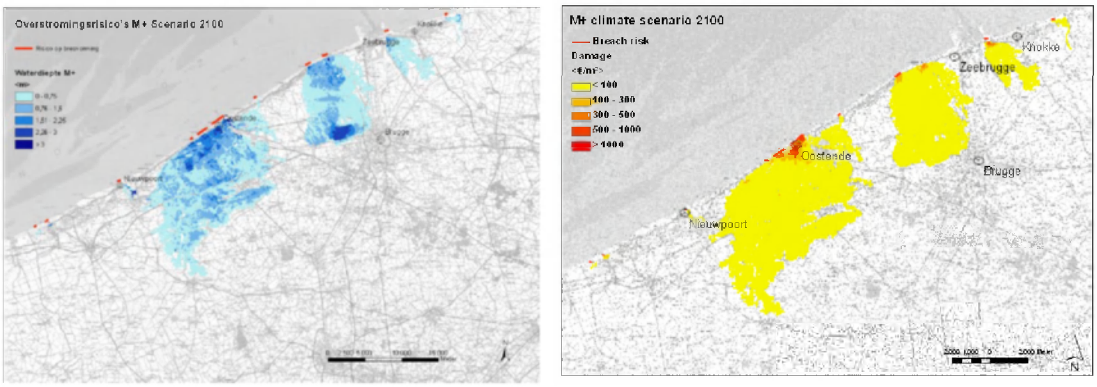

Figure 12: Results of the flood risk calculations for an extreme storm for the M+ 2100 scenario. Left: water depth, right: total damage.

Worst case scenario 2100

For the WCS 2100 scenario, the critical threshold volume necessary to prevent breach formation is reached in more then 50 % of the profiles. In some cases the crest of the sea defence is lower then the storm surge level even without erosion. This is the case for a majority of the beach towns, except for Koksijde, Nieuwpoort, Westende, Bredene (besides a few dune passages) and De Haan. The total damage cost is estimated at 1.7*10^{10} €, while the number of victims is estimated around 6700.

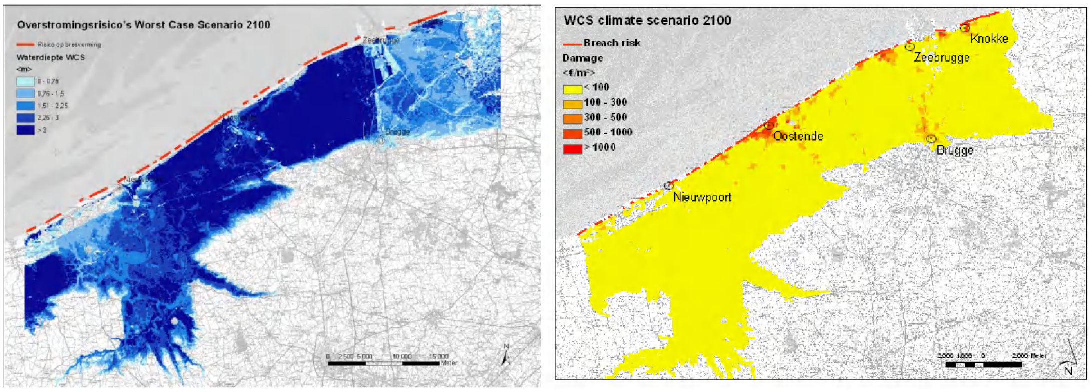

Figure 13: Results of the flood risk calculations for an extreme storm for the Worst Case 2100 scenario. Left: water depth, right: total damage.

Remark that ports are not taken into account within the flood risk calculations. They are considered a separate problematic requiring different types of models. Finally, when calculating flood risks on a future time scale of near 100 years an important factor of uncertainty on future socio-economic scenarios has to be taken into account.

4.2.3.3 Case study fisheries

4.2.3.3.1 Impact of climate change on fish stocks

The effect of climate change on fish and shellfish resources are/will be multifaceted and both direct and indirect. Apart from climate change, several other developments taking place simultaneously interact with possible climate effects (*e.g.,* fishing pressure). These impacts may occur on various levels of biological organisation including the individual, population and ecosystem and may vary between life stage, species and regions (Tulp *et al.*, 2006).

Marine fish populations are often large, have the opportunity to migration, have a high fecundity, different life stages, can be benthic or pelagic, and show natural fluctuations in stock status and year class strength.

Marine (shell) fish populations grow several orders of magnitude in size (from egg or larvae of 10^{-4} kg to an adult that may be ≥ 10^2 kg) and use different, often spatially segregated habitats within which they are exposed to a specific set of environmental abiotic and biotic factors. The various development stages have markedly different rates of growth and mortality as well as physiological tolerances to abiotic and biotic parameters like temperature, salinity, oxygen, prey availability, etc. (Tulp *et al.*, 2006). Therefore the effect of climate change on an **individual** level can be versatile and cause changes in behaviour and physiology.

Population persistence depends on life cycle closure and the availability of suitable habitats. Regional differences in the spatial and temporal extent of suitable habitats, population regulation and biological interactions among organisms (*e.g.,* predation and competition) may lead to population specific effects of climate change in a species. As the differences in life history traits and responses of vital rates (*e.g.,* growth mortality and reproduction) and physiology (bioenergetics) to abiotic and biotic factors the effects of climate change will be species specific (Tulp *et al.*, 2006).

On an **ecosystem** level bottom-up and bottom-down processes are influenced by physical factors like temperature and often involve non-linear processes. The strength of the temperature response of eco-physiological variables differ among species and taxa forming a food web/ecosystem (*e.g.,* phytoplankton, zooplankton, fish) and can lead to temporal and spatial (miss)match in the overlap of predators and prey or among rates of primary, secondary are tertiary production (Tulp *et al.*, 2006).

As the Belgian fleet operates in areas not considered by the other partners (see 4.2.1.2). ILVO-Fisheries gathered general information, when relevant, on climate change effects on fish stock in areas in which the fleet is/can be active. Table 8 summarises the scenarios of effects of climate change on European Seas.

Table 8: Summary of scenarios of effects of climate change on European Seas (Philippart *et al*., 2007)

General trends	Sea-specific expectations
Increase in temperature	Higher in northern than in southern seas
Impact on the ecosystems	Stronger for enclosed than for open seas
Northward movements	Stronger in southern than in northern seas
	Stronger in open than enclosed areas
Shifts in species composition	From Northern to southern species (open seas)
	From ice-bound to aquatic species (northern seas)
	From marine to freshwater species (Baltic Sea)
	From endemic to congeneric species (enclosed seas)

A study from (Perry *et al*., 2005) shows that the distribution of both exploited and non exploited North Sea fishes have responded markedly to recent increases in sea temperature, with nearly two-third of species shifting in mean latitude or depth or both over 25 years. For species with northerly or southerly range margins in the North Sea, halve shown boundary shifts with warming, and all but one shifted northwards. Species with shifting distributions have faster life cycles and smaller body sizes than non-shifting species.

Several studies (Dulvy *et al*., 2003; Rijnsdorp *et al*., 2008; Tasker, 2008) implement a fish specific approach and use the classification of fish species in ecotypes (Ellis *et al*., 2008). Ecotypes are groups of species that show similarities in certain biological characteristics, and therefore may respond in a similar ways to environmental change. Several aspects of life-history and demography can inform on the overall range of 'ecotypes' that may be considered within an overall fish community of an area, including their biogeographical affinity, reproductive mode, body size, trophic niche and habitat. Artic, boreal, Lusitanian, African and Atlantic species were identified.

A recent study, also using ecotypes, shows that many demersal and pelagic species changed abundance and distribution in all OSPAR regions (see Figure 9) (Tasker, 2008). Many of these changes were in accordance with what can be expected from climate change.

Two changes in distribution were apparent: a shift along the depth gradient and latitudinal shift. The whole North Sea fish assemblage has deepened (Dulvy *et al*., 2008) ~3.6 m per decade in response to climate change, and the deepening is coherent for most assemblage.

The latitudinal response to warming seas is more heterogeneous and is a composite of at least two patterns (Tasker, 2008):

- A northward shift in the average latitude of abundant, widespread specialists (*e.g.,* grey gurnard and poor cod);

- A southward shift of relatively small, abundant species with limited occupancy and northern range boundary in the North Sea (*e.g.,* sole, bib, solenette and lesser spotted dogfish).

The southward shift of warm-tolerant species in the North Sea is consistent with climate change acting trough:

- The warming and increased availability of shallow habitats in the southern North Sea;
- The NAO-linked inflows of warm water into north-eastern North Sea.

Further quantification will be based on the information available from literature study and modelling work currently undertaken by several (ICES) scientists and working groups.

4.2.3.3.2 Interaction of climate change and fishing pressure

Fishing and climate forcing interact on individual fish, marine populations, marine communities, and ecosystems to bring these levels into states that are more sensitive to (*i.e.*, more strongly related with) climate forcing (Perry *et al*., 2009b). Fishing is unlikely to alter the sensitivities of individual finfish and invertebrates to climate forcing. It will remove individuals with specific characteristics from the gene pool, thereby affecting structure and function at higher levels of organisation. Fishing leads to a loss of older age classes, spatial contraction, loss of sub-units, and alteration of life history traits in populations, making them more sensitive to climate variability at interannual to interdecadal scales. Fishing reduces the mean size of individuals and mean trophic level of communities, decreasing their turnover time leading them to track environmental variability more closely. Marine ecosystems under intense exploitation evolve towards stronger bottom-up control and greater sensitivity to climate forcing. Because climate change occurs slowly, its effects are not likely to have immediate impacts on marine systems but will be manifest as the accumulation of the interactions between fishing and climate variability, unless threshold limits are exceeded.

Note that most commercial fish stocks are managed based on the advice given by the ICES working groups which use the ICES areas as geographical and biological reference. Since most stocks important for Belgian fisheries are exploited by several countries —based on the quota assigned by the European Commission — make it almost impossible to develop adaptation measures focussing on (individual) stocks on a national level. The fact that many of these international fishing fleets practice a mixed fishery, like Belgium, even complicates the issue.

4.2.3.3.3 Effect of climate change on some commercial species (potentially) important for Belgian fisheries

There are strong indications that the ecosystem in general and the (commercial) fish stocks especially were, are and will be affected by climate change (Brander, 2007; Cook and Heath, 2005; ICES, 2008c; Philippart *et al*., 2007; Tulp *et al.*, 2006). The spatial distribution and/or recruitment of species important for the Belgian fisheries like sole (Rijnsdorp, 2008), plaice (Perry *et al*., 2005; van Keeken *et al*., 2007) and cod (ICES, 2002) were already affected by climate change. More southern commercial species, like red mullet and John Dory, which are currently not important for Belgian fisheries but have a high economic value and are still quota free species, are likely to increase their northerly presence in response to climatic warming (Engelhard *et al.*, 2008b). Further temperature rises are likely to have profound impacts on commercial fisheries through continued shifts in distribution and alterations in community interaction (ICES, 2008a; Perry *et al*., 2005).

In the report solely focusing on the fisheries case study, the effect of climate change on stocks of (potentially) commercial species for Belgian fisheries are described in detail and continuously up-dated as new research result from (ICES) workgroups and specialised scientists is published. The final version of this comprehensive document is planned for the end of the second phase of the CLIMAR-project, a draft version is already available for internal use.

In this report (final report phase 1) the effect of climate change on 3 species, each representing a typical case, is summarised:

- Sole (*Solea solea*) was selected since this flatfish is the main target species of the Belgian fleet.
- Cod (*Gadus morhua*) was selected as the effect of climate change on the commercially exploited stocks is already well documented. This round fish species shows that although long term datasets and plenty of background information is available, it is not easy to formulate univocal conclusions, predictions and recommendations.
- Red mullet (*Mullus surmuletus*) was selected as potential new target species as the combination of the high market value of this quota free species and its potentially increased presence in northern parts of its distribution range (Engelhard *et al*., 2008a).

4.2.3.3.3.1 Sole (Solea solea):

Sole is an important and valuable species for Belgian fisheries. The main sole fishing countries are Belgium, the Netherlands and France (Tessens and Velghe, 2008).

Sole (*Solea solea*), sometimes cited as *Solea vulgaris*, is a Lusitanian species (Ellis *et al.*, 2008) and tends to occupy shallow, sandy/muddy habitats. Although such habitats are widespread in the North Sea and the spawning occurs all along the southern coasts, five main spawning grounds can be distinguished: the inner German Bight, off the Belgian coast, in the eastern Channel, in the Tames estuary and on the Norfolks banks (ICES, 2009). Sole spawns in the late winter and spring. The spawning peak in the Bay of Biscay is earlier than in the south-eastern North Sea (March versus late May) (Rijnsdorp, 2008).

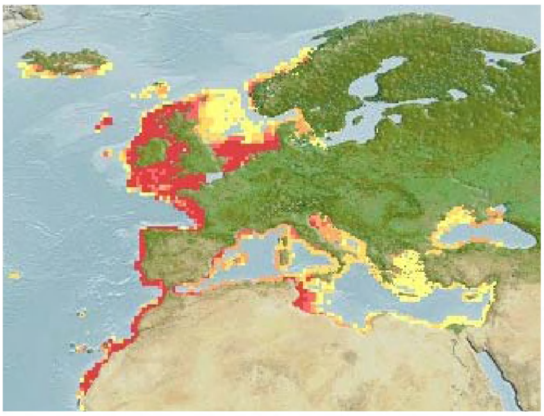

Figure 14: Computer Generated Native Distribution Map of *Solea solea* (reviewed). Data sources: GBIF OBIS, from www.aquamaps.org.

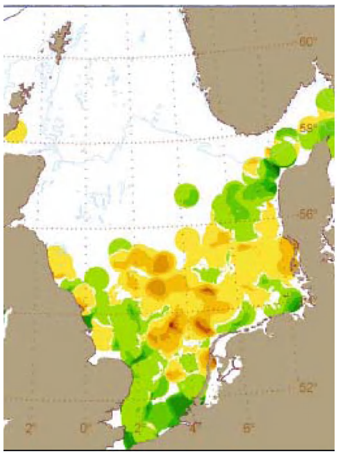

Figure 15: Change in distribution of *Solea Solea* between 1977-1998 and 200-2005 in the North Sea, quarter 1 (blue to green: increase in density, yellow to red: decrease in density) (ICES, 2008c)

In OSPAR regions II and III sole showed the expected response, namely a southward shift (Tasker, 2008). A study from Perry *et al.* (2005) analysing the shift of centres of distribution of many species showed for sole in the North Sea an unexpected shift to the south. The explanation given by the author, namely that improved environmental conditions in the rivers, is not always supported by other scientists (Rijnsdorp, 2008). This shift to the south was also reported by the ICES Working group on Fish ecology (WGFE) and is consistent with a reaction to warming in the southern North Sea (ICES, 2008c).

Climate change is expected to affect sole populations through a number of different mechanisms. The most important environmental factors involved are temperature and river run-off; Warmer conditions will improve the survival of demersal stages as the probability of high winter mortality due to cold

winters will decrease; This will particularly apply to northern areas characterised by a relatively large amplitude in temperatures. The timing of spawning, in particular in areas such as the North Sea where the amplitude of the seasonal cycle in water temperature is relatively large, will be advanced resulting in a longer growth period for the 0-group fish. In combination with higher temperatures during the growing period this will result in a higher growth rate. In sea areas such as the Mediterranean and Bay of Biscay (Le Pape *et al.*, 2003), where the size and quality of the nursery grounds are affected by river run off, changes in rain fall and river run off will impact recruitment and growth. How climate change will affect the pelagic life stages and their transport to the coastal nursery grounds remains to be studied. The temperature tolerance limits of eggs and larvae do not suggest that an increase in temperature will have a significant impact. The above conclusions are uncertain as it is unknown how an increase in temperature will affect productivity of pelagic and benthic food (Rijnsdorp, 2008).

4.2.3.3.3.2 Atlantic cod (Gadus morhua):

Cod is a boreal species and is a top predator inhabiting the northern temperate and cold waters of the Atlantic (Engelhard *et al.*, 2008c).

The ICES workshop on the ‘Decline and Recovery of cod Stocks throughout the North Atlantic, including tropho-dynamic effects (WKDRCS) (ICES, 2006) and the ICES/GLOBEC Working Group on Cod and Climate Change (WGCCC) (ICES, 2007) state that both fishing and climate are implicated in the declines in cod stock biomass since 1970. It is not possible to make a quantitative attribution and the factors, *e.g.,* effective environmental factors include plankton production (*e.g., Calanus finmarchicus* versus *Calanus helgolandicus*) and other ecosystem effects, interact, and often co-vary with temperature change, making it difficult to separate them from direct effects of temperature on growth, survival and recruitment.

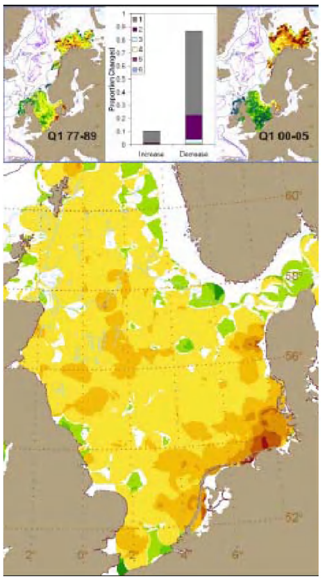

Figure 16: Change in distribution of *Gadus morhua* between 1977-1998 and 200-2005 in the North quarter 1 (blue to green: increase in density, yellow to red: decrease in density) (ICES, 2008c)

Cod has decreased significantly in the North Sea between 1977-1998 and 2000-2005 (

). The reduction density was highest to the southeast along the Dutch coast where density decreased by about a factor of 100, while a limited increase was observed along the north-eastern fringe. An increase in density was observed over 11 % of the survey area and a decrease over 87 %. In the North Sea, a northward shift in the mean latitudinal distribution of cod has occurred but there is much controversy as to the causes. Causes could include active migration (now considered unlikely), higher fishing mortality in the south, local differences in recruitment or a mixture of this and other causes (Engelhard *et al*., 2008c).

Recruitment is negatively related to temperature in more southerly populations, but positively in the northern ones, with no significant relationships recorded for some stocks at intermediate latitudes. A warmer climate may have a subtle, positive effect on growth. For Baltic and North Sea cod, several authors have studied the implications of projected climate change for future fishery management: where an important point of agreement was that fishing mortality needs to be reduced at short-medium term, with climate change potentially kicking in on the longer term (Engelhard *et al*., 2008c).

4.2.3.3.3.3 Red mullet (Mullus surmuletus):

The distribution of red mullet (Lusitanian species) extends northwards into coastal waters of Norway, northern Scotland, and to the Faroe islands, southwards to the Strait of Gibraltar and into the Mediterranean and Black seas, and also along the coast of Northwest Africa to Senegal and the Canary Islands.

Red mullet has a relative fast growth rate and a planktonic egg life-phase, which may make it more capable to rapid response to climate warming by colonising new habitats. The high market value of this non-quota species, its increased presences in northern parts of its distribution range (including the North Sea) in response to climate change, in combination with the likelihood of a more targeted fishery in the future make red mullet a highly relevant case study in the context of climate change and fishery management (Engelhard *et al*., 2008a).

4.2.3.4 Case study tourism

Based on the priority score (as described under methodology) the following risks and their indicators were selected for the sector Tourism (Table 9). These are further discussed in detail in the subdocument Tourism (Volckaert *et al*., 2009). Besides a brief argumentation can be found in the subdocument of the identified risks not hold back for further quantification.

Table 9: Selected main risks and their indicators (Sector Tourism)

Effect category	Effect	Direct / Indirect	Related to	Indicator
Ecological - Habitat Change	Coastal erosion (loss of beach & dune area)	Direct	Beach tourism Eco tourism	% of the coastline that is eroding or loss of beach surface area / municipality / year
Ecological - Geographical Shift	Increase of sea mammals	Direct/ Indirect	Eco tourism	# sea mammals observed in the coastal & marine

				zone (incl. Westerschelde).
Social - Attractiveness	Attraction value coast	Direct	All sectors	Tourist Climate Index
Social – Accessibility	Accessibility coast by road or public transport	Indirect	All sectors	cost of travel time = f(travel intensity, damage coastal infrastructure.
Social/Economical – Safety/ damage costs	Loss/ damage to marina's, accommodations	Direct	Water tourism Commercial tourism	Loss or damage to berths and moorings for recreational boating per marina.
Economical – Economic result	Turnover of tourism sector	Indirect	All sectors (focus on commercial tourism)	Overall turnover tourism sector
Economical – New opportunities	New commercial activities	Indirect	Water tourism Eco tourism	Turnover new commercial activities (ecotourism)

5 Decision making and action planning (adaptation)

Adaptation is a process by which strategies aiming to moderate, cope with, and take advantage of the consequences of climate events are enhanced, developed and implemented. A climate adaptation strategy represents a combination of measures and options chosen to meet a particular risk.

5.1 General identification of adaptation measures

5.1.1 Typology

Following the precautionary principle, numerous adaptation measures, both structural and non-structural, are being developed in Belgium. In order to structure the possible portfolio of measures to be considered the following typology will be used within CLIMAR. For each adaptation type some measures have been given as example.

Table 10: Typology of possible adaptation measures for marine activities

Adaptation type	Description Examples of measures for the BPNS marine activities
Share loss	*Insurance type strategies.* Install a tourist climate change contribution for overnight stays to raise funding for climate change effects or installing adaptation measures. Increase the risk premium (natural risks) for inhabitants subject to a higher risk of coastal flooding. Look for other activities for the fishing boots (*e.g.*, touristic activities) Insurance of other sharing mechanisms between ship owners, harbour authorities, others for increased risk of ship damage due to storm activities. Risk maps: maps with indication of risk zones to aware the people. People live in risk zones on their own responsibility. Government could stimulate relocation inland by granting subsidies.
Bear losses	*Simply bear losses where losses cannot be avoided:* Loss of coastal areas to sea level rise and/or increased rates of coastal erosion - beach nourishment techniques are needed on a chronically basis. Further decrease of the Belgian fishing fleet. Less shipping traffic due to increased storm weather conditions.
Prevent the effects. Structural and technological.	*Hard engineering and technical solutions* An integrated coastal defence plan ("Kustveiligheidsplan") to protect the coastal zone against flooding on short (anno 2010) and long term (anno 2050); so taking into account sea level rise by climate change, is being worked out; possible technical measures

	are heightening of dikes, beach nourishment, groynes, … Technical adaptation of fishing boots and fishing gear to the changed weather conditions and changed fishing population. Improve the safety on board of fishing boats during storms. Providing technical assistance in design standards for marina and harbour piers and realising adapted harbour piers and docks. Multifunctional islands, floating breakwaters, super dike, very large beaches / sand motor.
Prevent the effects: Legislative, regulatory, institutional	*Series of legislative, policy, … instruments to prevent effects and to accompany technical measures* Amend design standards (*e.g.,* building regulations) and enforced compliance. Designing & implementing standards for minimum floor level heights and other flood resistant measures for buildings in areas at risk of coastal flooding. The possible new "zeeweringsdecreet" (to be checked) Revised "Rampenplan Noordzee" Change fish quota and discard ban in response to climate change induced changes in the fish population. Climate change management plan in harbours (*e.g.*, contingency activities). Contingency plans to become climate-proof: restriction to new developments in risk zones, evacuation plans, waterproof ground floor.
Avoid changes	*Avoid the negative impact of climate change by "moving" the at risk object of person* Moving (tourism) infrastructure further back from the coast or move away from specific at higher risk locations; Divert to other fishing grounds. Divert shipping traffic to harbours less exposed to the increased storm weather conditions.
Exploit opportunities	*Benefit from the positive impact of climate change* Adaptation of the fisheries fleet to new species Increase the tourist capacity (more tourists, longer season) Increase harbour traffic by adapting to the increased tidal window (sea level rise induced) Managed retreat: nature development
Research	Although the importance of research on climate change effects and measures cannot be overemphasized, it is proposed not to consider it as a separate measure in the climate change strategy,

	as in most cases research will lead to a portfolio of other measures, described above, and it is virtually impossible to derive and evaluate the socio-economic impact of the research measure as such. Hence, the cost and effect of research activities will be embedded within the other measures.
Education & communication Behavioural	Although educational measures and measured to influence behavioural change will be needed, it is proposed not to consider these measures as a separate type in the structure, as in most cases educational and behavioural change measures will accompany other measures, described above, and it is virtually impossible to derive and evaluate the socio-economic impact of educational and behavioural change measures as such. Hence, the cost and effect of measures related to education and behavioural change will be embedded within the other measures.

The selected adaptation measures will further be described using a standardised format: the Adaptation Measure Fact Sheet (AMFS) including: Definition of the adaptation measure; Categorisation; Possible side effects; Investment & operating costs; Policy Relevance; Implementation.

The identification of the adaptation measures will be the result of available literature, expert knowledge and participatory approach (workshops). Currently a workshop has taken place for the two case studies: coastal flooding and fisheries (see further: Participation).

5.1.2 Pre-assessment of the adaptation measures

The identified adaptation measures will be subjected to a multi criteria analysis on the level of the adaptation measure in order to select the most efficient measures as starting point for the adaptation strategy.

The multi-criteria analysis shall be based on a number of important characteristics of the adaptation measures. These criteria will be the result of a literature study of existing analysis tools and public participation (experts).

- Following criteria will be taken into account:
- Risk reduction
- Position in the DPSIR (Driving forces, Pressures, States, Impacts, Responses) chain
- No-Regret measures
- Ecosystem approach
- Multi-sectoral character of measures
- Other criteria

Each of the criteria will be given a weight as a function of their importance. A weight of 1 can be given to all criteria if all parameters are evaluated as being as important. If the different criteria are evaluated as unequal, than a qualitative weight-scale of 1 (less important) to 3 (highly important) can be chosen. The combination of the criteria and their weights (multi-criteria analysis) will result in an effectiveness scaling of the identified adaptation measures.

5.1.2.1 Case study coastal defence

The development and pre-assessment of the adaptation measures is based on literature review and on stakeholder involvement through an interactive multisectoral workshop (see 5.3.1). The thus identified adaptation measures are projected onto the Belgian coastline. Composite maps of land use and flood risk are used to define which type of defence measure is most feasible for every specific coastal region in Belgium and to identify possible conflicts between alternative defence measures and land use developments. More information on the measures and their projection onto the Belgian coastline can be found in Van der Biest *et al.* (2009b).

5.1.2.1.1 Artificial islands

The idea is to construct one or more islands in front of the coast which can be used for other purposes besides coastal defence, such as wind farms, storage reservoir, anchorage of wave absorbers, aquaculture development, tourist attraction, nature development…In order to reduce the costs for protection of the islands against flooding, it is favourable to use the islands for activities that are not impeded by occasional flooding. The location of the islands could be based on the natural geomorphology of the Belgian continental shelf (BCS) in order to reduce the amount of construction material needed.

One of the major uncertainties of this defence strategy is the influence on erosion of the shoreline and on the morphology of the BCS. The islands are able to protect beaches locally and they will even create larger beaches due to sedimentation in the lee of the islands. But this could exacerbate erosion further down the shoreline where the sand would be deposited under normal circumstances. For example, beach accretion in the lee of the artificial Palm Island I in Dubai is in the range of 30 metres per year (Smit *et al*., 2005). The downdrift erosion rate is estimated to be 50 metres every two years by the monitoring program of the Coastal Management Section of Dubai Municipality.

Furthermore, it is a very costly strategy due to the large amounts of construction material needed and the protection of the islands against erosion. According to the Second Deltacommission, a series of islands of 100 kilometres long, 6 kilometres wide and 25 metres above the sea bottom in front of the Dutch coast would request a total amount of 15 to 20 billion m³ material.

Besides, the islands are no solutions for scenarios of sea level rise. They should be raised on a regular basis in order to keep its protective function as sea level rises. From tourist point of view doubts might be expressed on the disturbance of the typical infinite view along the Belgian coastline. The islands might also impede shipping traffic.

5.1.2.1.2 Breakwaters

Breakwaters or artificial reefs are used to attenuate wave energy at breaking in order to reduce structural erosion of beaches and dunes or dikes. The most common breakwaters are hard structures made of rocks or concrete and deposited on the sea bottom. The main problem for using hard reefs along the Belgian coastline is the high tidal range. The average difference between low tide and high tide measures nearly 4 meters. In order to be able to absorb wave energy during high tide the reefs have to be sufficiently high. But then they will rise high above the water during low tide. In addition, during an extreme storm with a storm surge up to 6 meter TAW, they will not be able to absorb wave energy at all.

An alternative for fixed reefs are floating breakwaters. They float on the water surface so there functioning is independent of tide, surge and sea level rise. In order to keep them on the right location, they can be attached to the sea bottom with mooring cables. Floating breakwaters could be placed anywhere along the coastline as long as they don't obstruct shipping traffic. They are less expensive then solid breakwaters and they don't disturb currents and sediment movements. Furthermore, they can become more cost-efficient if they are used to anchor wave absorbers for the production of electricity.

5.1.2.1.3 Super dike

A super dike is a very broad dike for which the chance of breaching during an extreme storm under the worst case scenario of climate change by 2100 is almost inexistent. The dike could be up to a few hundred meters broad and should be heightened to anticipate sea level rise by the year 2100. The inland part of the dike could be used for housing, parks, recreation... The exact interpretation of the use and morphology of the super-dike depends on the spatial characteristics of the site where it will be implanted.

However, the main problem in Belgium is the lack of space to construct such a broad dike. The only possibility would be to place the dike seawards from the present sea wall. The dike itself could be protected against storm damages by sand nourishments in front of the dike. Due to the heightening of the dike the sea view from the present promenade and from the ground floor will be disturbed. Alternatively, the disturbed view could be compensated for by covering the hard dike with dunes, after the example of “dike in dune” at Noordwijk, Netherlands.

According to recent research in the Netherlands a super dike reduces the risk of flooding with a factor 100 (Silva and van Elzen, 2008). Furthermore, a super dike also creates new opportunities for recreational activities on the promenade or for nature development in the dunes.

5.1.2.1.4 Very large beaches / sand motor

The idea of very large beaches follows naturally from the present policy of coastal protection where preference is given to soft defence measures. The present technique of sand suppletions should be intensified so that the coastline gradually migrates seawards. The yearly amount of sand supply should be more then needed for safety only so that new opportunities arise for recreation and tourism. This adaptation measure is recommended by the Second Deltacommission for large parts of the Dutch coastline. They propose to supply beaches gradually up to 1 kilometre seawards by the year 2100.

The main advantages of this defence measure is that it is a more natural technique and that it can grow with the sea level rise unlike hard defence structures. The natural ecosystem also has the opportunity to adapt itself to the gradual expansion of the beaches. On the other hand, it requires enormous amounts of sand and it is not certain whether this sand can be found on the BCS.

A sand motor could be an alternative method to gradually create very large beaches. The sand motor is a huge amount of sand deposited in the sea close to the coast. Natural processes such as wind, waves and currents disperse the sand along the coastline. The beaches gradually extend seawards in a natural way so the coastline is better protected against flooding. In the Netherlands, a pilot project of the sand motor will be started in 2010, off the Delfland coast.

5.1.2.1.5 Large-scale managed retreat

Besides an extension of the existing areas of managed retreat and the declaration of new areas for managed retreat, it might be considered to adopt managed retreat on a large scale in the more extreme climate scenarios. While in the current areas of managed retreat flooding is controlled, managed retreat on a large-scale implies unimpeded flooding of the low-lying hinterland. The polders behind the first defence line are used as inundation area and will act as sediment trap. The gradual elevation of the polders will help to protect inland towns and industry against flooding.

The main drawbacks of this measure are the loss of valuable farmlands and the need to abandon scattered properties in the polder landscape. It might also be necessary to abandon seaside resorts and relocate them inland. From natural point of view it has the advantage that new opportunities will be created for the development of coast specific habitats.

5.1.2.1.6 Preparedness: become climate-proof

Instead of thinking in terms of defence only, people should be aware of the potential risk of flooding and be prepared for an emergency. This scenario suggests a shared responsibility between people and government. People should accept that governments can not guarantee full protection against flooding under extreme circumstances. The people themselves should try to reduce their own risks and be responsible for their lives and properties.

The task of the government would then consist of drawing up effective and up to date contingency plans. They have to inform the people on the risks they run; stimulate the people to reduce their own risks; alert the people in case of emergency and draw up evacuation plans. For example, maps with indication of flood susceptible areas could be distributed to inform people about the risk of living in certain areas.

People who live scattered in high risk zones could be stimulated by the government to abandon their homes by granting a subsidy. The government could also constitute a law that forbids people to construct new houses within a strip of 100 meter inland from the dune foot.

Insurance companies could offer flood insurances to people living in risk zones. This may also help to increase awareness of danger amongst people.

Existing houses can be made climate-proof. For example, the ground floor could be made waterproof by relocating accommodations and valuable objects to upper floors. The ground floor could then be used as garage (if cars can be replaced to safe locations in case of flood warning), or as display window for shops, bars, restaurants and offices. A removable floodgate might be used to block streets to prevent inland flooding.

5.1.2.2 Case study fisheries

Based on the findings described earlier, the consequences of climate change for the fleet will detailed on a biological, technological, economical and social level, and the elaboration of scenarios for these secondary impacts at different points in time (2040, 2100) is ongoing. Scenarios serve as a basis for identifying possible responses of the fisheries sector. Possible measures such as changing the operation and the structure of the fleet, divert to other fishing grounds, opt for other target species and/or fishing methods will be described and included in the adaptation strategies. Such adaptation strategies will take into account the biological, technological, economical and social implications and will be evaluated on their sustainability using an evaluation framework. The adaptation strategies recommended at the end of this whole process should contribute to the development of the Belgian fishery into an innovative, flexible and durable activity; able to cope with changing circumstances, including climate changes.

Variability on a range of time-scales has always been a feature of fisheries, especially capture fisheries. Where there is effective management in place, fisheries systems have developed adaptive strategies and through monitoring and feedback, fishing effort and catches are regularly modified according the state of the stock. In these cases, the fishing community must have either the robustness or flexibility (or both) to absorb the changes in resource abundance so as to avoid negative ecological, social or economical impacts. Robustness is typically associated with factors such as total fishing capacity being commensurate with the productive capacity of the resource during its lower productivity phases, the availability of alternative fishing resources, investments in flexible technologies such as multipurpose boats (as opposed to specialised vessels) and flexible processing chains, or the ability and opportunity to alternative livelihoods during lean periods (FAO, 2007).

The response of fishing communities to global changes can differ (Perry *et al.*, 2009a) Several studies illustrate the general statement that resource-dependent communities seek to increase their adaptive capacity through flexibility in the human subsystem that enables responses to significant changes in the natural subsystem.

- At a short term scale, fishing can be intensified, target species and fishing method can be diversified, or the fleet can decide to 'hibernate'. These measures/strategies can be considered as a coping measure/strategy.
- At longer time scales the implementation of adaptation measures/strategy can be considered. The fleet/fishing community can change to other fisheries, upgrade its skill and/or education, improve their networking, opt for another industry, political action or decide to terminate its activities.

Guidance and (financial) assistance from policymakers throughout the adaptation process should aim at mitigating the negative effects of climate change and help to make the most of the opportunities offered. In principle these measure/strategies can be developed on a global, European, national, regional or even individual level.

Most commercial fish stocks are managed based on the advice given by the ICES working groups which use the ICES areas as geographical and biological reference. Stocks important for Belgian fisheries are exploited by several countries, based on the quota assigned by the European Commission. As a consequence, the majority of regulations affecting the Belgian fleet are issued by the European Commission, leaving not much room for national policymakers to implement own regulations which could support adaptation strategies.

In a Belgian context these adaptation measures and strategies will act by changing the operational functioning and structure of the fleet. ILVO-Fisheries started compiling data on alternative fishing methods applicable in the Belgian context as input for the development of adaptation strategies. Active fishing methods (alternative beam trawl, outrigger, twin rigger, flyshooting, seines, etc.) and passive methods (gillnets, entangling nets, hooks, lines, traps, etc.) will be addressed.

5.2 General identification of adaptation strategies

Finally, the measures will be combined as (inter)sectoral adaptive strategies. The success of the full strategy depends on numerous factors such as the effectiveness of the measures, the acceptance of the introduction, the potential for benefits that outweigh the costs, the consistency of the measures with other sectoral initiatives, etc.

Different adaptation strategies ("scenarios") can be defined:

- Business-as-usual scenario: consisting of the most commonly used adaptation measures, so with the emphasis on bear loss, shear loss and technical measures;
- Adaptive approach: gradual adaptation strategy starting with a common combination of adaptation measures on a short term, but giving the possibility to diversify to a certain direction as more information about *e.g.,* climate impacts or socio-economic scenarios become available;
- Reactive approach: fixed adaptation strategy for mid and long term, with the risk on a 180° switch if new information becomes available;
- …

These different adaptation strategies will further be subjected to a multi-criteria analysis on this grouped level of measures.

5.3 Public participation

As for many measures related to sustainable development, the success of the implementation of adaptive strategies will depend on the understanding by the civil society and private organisations of the importance of these strategies. It is, in other words, not sufficient to look at adaptation measures only from a technical perspective of sustainability. Measures that are effective (in terms of reducing risk) in theory, can turn out having a lot of implementation problems due to the lack of social acceptance. It is therefore preferable to involve stakeholders, again at the earliest possible stage, in the process of identifying the problem and the possible adaptive strategies, by different means of participation (*e.g.,* interviews, via workshops).

Communication and interaction with the stakeholders is crucial for:

- Data delivery and information about effects;
- The identification and selection of relevant adaptation measures;
- The evaluation of the adaptation strategies; specifically in the step of determining the parameters and their weights for the multi-criteria analysis.

Two workshops have been organised in 2008. More information can be found on the CLIMAR website http://www.arcadisbelgium.be/climar/.

At the end of the CLIMAR project a third workshop will be organised.

5.3.1 "De Kust op maat van het klimaat" (Coastal flooding)

The first workshop "De Kust op maat van het klimaat" took place on Thursday 4 December 2008 at the InnovOcean site, Oostende (Belgium). The workshop was organised in cooperation with the "Coördinatiepunt Duurzaam Kustbeheer" and with the "MDK-afdeling Kust" (the administration responsible for the coastal defences). The workshop aimed at bringing together representatives from different coastal sectors and to create an interactive debate on how to deal with the possible impact of climate changes on coastal flood risks and the possible adaptation strategies.

During the morning session the participants were introduced into the world of sea defence and climate change problematic. Following topics were presented:

- Kathy Belpaeme - De kust op maat van het klimaat (introduction to the workshop)
- Renaat De Sutter - Klimaatverandering - gevolgen en maatregelen (presentation of the CLIMAR-project)
- Katrien Van der Biest - Klimaatverandering en overstromingen (presentation of the intermediate results of the case-study coastal flooding)
- Tina Mertens - Werken aan een veilige kust in 2050 - Geïntegreerd Kustveiligheidsplan (presentation of the present-day coastal defence policy in Belgium)
- Jos Van Alphen - Een land dat leeft, bouwt aan zijn toekomst (outcomes of the Second Deltacommission on future coastal safety in the Netherlands)

The afternoon session was moderated by Kathy Belpaeme and Hannelore Maelfait (Coördinatiepunt Duurzaam Kustbeheer), Ann-Katrien Lescrauwaet (Vlaams Instituut voor de Zee), An Cliquet (Maritiem Instituut UGent) and An Vanhulle (Grontmij). In a first session, the participants were divided into groups of the same sector. They were asked to put forward alternative ideas to adapt to the effects of climate change on coastal erosion and coastal flood risks. In a second session the groups were reorganized so that each group has at least one representative from each coastal sector. The suggestions from the first session were then presented to the multi-sectoral groups. Each of the participants was asked to express the possible side-effects, positive or negative, of the measure on their sector.

Conclusions:

- combination of several measures is expected to be most effective
- along the Belgian coastline, inland solutions seem to be rather difficult due to the lack of space
- alternative defence measures seem to offer a lot possibilities for win-win situations with other sectors such as energy, tourism, agriculture, aquaculture,…
- multi-criteria, cost-benefit,… analyses are necessary to evaluate all the possible side-effects and opportunities of the measures

5.3.2 "Crisis in de Visserij: Keert klimaat het tij?"/ "Crisis in fisheries: does climate turn the tide?"

The second workshop "Crisis in de Visserij: Keert klimaat het tij?" took place on Tuesday 9 December 2008, ILVO-fisheries, Oostende (Belgium). This workshop dealt with the impact of climate changes on the fisheries sector, future developments in de fisheries sector and the possible adaptation strategies.

The interest in the workshop was high, as 73 participants attended the event, and all the requested stakeholders for the round-table were present. Based on the conducted survey (60 respondents) the participants could be spilt as follows: producers organisation (7%), ship-owners (8%), policy (18%), scientific research institutes (23%), distribution chain (2%), conservation organisation (5%) and other (25%) (blank: 12%).

The work executed in the framework of the project was presented by the partners in the morning session:

- Renaat De Sutter - Klimaatsverandering: gevolgen en maatregelen
- Dries Van den Eynde - Primaire effecten klimaatsverandering: synthese en modellering
- Els Vanderperren - Gevolgen klimaatsverandering voor de visserij
- Frank Maes - Wettelijk kader visserij: wat te verwachten?

The questions asked by the public showed a genuine interest in the subject.

The afternoon session, moderated by Prof. Frank Maes, started with a round-table with different stakeholders: Departement Landbouw en Visserij (Marc Welvaert), Rederscentrale – Regionale Advies Raad (Emiel H. Brouckaert), Centrale Raad voor het Bedrijfsleven (BRC Visserij) (Manu Desutter), ILVO-Fisheries (Hans Polet), Marine Harvest (Anje Mattheeuws and Bertil Buysse), Natuurpunt (Bart Slabbinck), Stichting voor Duurzame Visserijontwikkeling – Regionale Advies Raad (Luc Corbisier) Vlaams Instituut voor de Zee (Jan Seys).

Each stakeholder presented his/her organisation and shortly expressed their view on the future of the Belgian fisheries sector, focussing on the effect of climate change and possible adaptation strategies. Subsequently, a constructive discussion addresses the possible impacts of climate change on the fisheries sector, expected developments in the fisheries sector and the development of adaptation strategies.

The preliminary results of a short survey conducted when the participant arrived were presented but not discussed.

Conclusions:

The high attendance and constructive discussion between the different stakeholders indicates that the general mentality is changing. Summarised, the following can be concluded:

- The complexity of the Belgian sea fisheries sector and the ecosystem hamper the assessment of the impacts of climate change and the development of adaptation strategies, especially on the long-term.
- The Belgian fisheries fleet has a future, yet diversification and reengineering is needed.
- The ecological, economical and social aspects are equally important for the development of the sea fisheries into a sustainable activity.

6 Evaluation of adaptation scenario's

6.1 Policy and legal evaluation of adaptive strategy

6.1.1 The International policy on Adaptation

So far, the international climate effort has generally focused on mitigation – reducing greenhouse gas emissions to prevent dangerous climate change – rather than adaptation. Hence adaptation together with mitigation is an important response strategy. Without early and strong mitigation actions the costs of adaptation will inevitably rise (Stern, 2007). The Assessment reports of the IPCC on climate change indicate that effects of climate change are taking place and action to avoid further dangerous effects is urgent. Equal attention need to be paid to adaptation strategies.

At the international centre of efforts to address climate change is the 1992 United Nations Framework Convention on Climate Change (UNFCCC)[1]: "*The UNFCCC provides the basis for concerted international action to mitigate climate change and to adapt to its impacts. Its provisions are far-sighted, innovative and firmly embedded in the concept of sustainable development*" (UNFCCC, 2006). The UNFCCC sets the overarching objective for multilateral action: to stabilise greenhouse gas concentrations in the atmosphere at a level that avoids dangerous anthropogenic climate change. It also establishes key principles to guide the international response, in particular that countries should act consistently with their responsibility for climate change as well as their capacity to do so, and that developed countries should take the lead, given their historical contribution to greenhouse gas emissions (Stern, 2007).

Besides mitigation, several articles of the Convention deal explicitly with adaptation.

According to the UNFCCC, all Parties – in addition to the development of national greenhouse gases inventories and climate change mitigation measures- shall:

- "take precautionary measures to anticipate, prevent or minimise the causes of climate change and mitigate its adverse effects . . . To achieve this, such policies and measures should take into account different socio-economic contexts, to be comprehensive, cover all relevant sources, sinks, and reservoirs of greenhouse gases, and adaptation (Article 3, Section 3).
- formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change . . . and measures to facilitate adequate adaptation to climate change (Article 4, Section 1 (b)).
- cooperate in preparing for adaptation to the impacts of climate change; develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods (Article 4, Section 1 (e)).
- take climate change considerations into account, to the extent feasible, their relevant social, economic and environmental policies and actions, and employ appropriate methods, for example impact assessment, formulated and determined nationally, with a view to minimising adverse effects on the economy on public health, and on quality of the environment, of projects or measures

[1] Framework Convention on Climate Change, United Nations, FCCC/INFORMAL/84, 9 May 1992, *B.S.* 2 April 1997.

undertaken by them to mitigate or adapt to climate change (Article 4, Section 1(f)).”

In addition to the appropriate adaptation measures that the parties should take for their own country, the parties are also obliged to support developing countries in the development of adaptation measures:

“All Parties are required to take the actions necessary related to funding, insurance and the transfer of technology, to meet the specific needs and concerns of developing countries arising from the adverse effects of climate change (Article 4, Section 8) and to take full account of the specific needs and special situations of the least developed countries in their actions with regard to funding and transfer of technology (Article 4, Section 9). In addition, developed countries are required to assist developing countries in meeting costs of adaptation to the adverse effects of climate change (Article 4, Section 4).”

These references to adaptation constitute only a small part of the Framework Convention, which is primarily devoted to *“stabilisation of greenhouse gas concentration in the atmosphere”* (Article 2). However the Third and Fourth Assessment Report of the IPCC has resulted in initiation of discussions on adaptation as well. To this the Conference of the Parties (COP) to the UNFCCC has made several decisions in regards to adaptation to climate change. Most relate to the assessment of adaptive capacity of developing countries and providing funds for adaptation efforts in least developed countries. This is elaborated in the Nairobi Work Programme adopted by the Conference of the Parties to the UNFCCC in 2005[2] and renamed in 2006. At COP 13, held in December 2007, the UNFCCC developed a roadmap for a post-2012 climate regime, comprising the Bali Action Plan, with adaptation as one of the four building blocks along with mitigation, finance and technology.[3] With respect to developed countries, they have the obligation under Article 4 of the UNFCCC to launch an adaptive strategy as an adequate response to climate change. The same commitment is reflected in Article 10 of the Kyoto Protocol[4] to the Framework Convention: *“. . . Formulate, implement, publish and regularly update national and, where appropriate, regional programmes containing measures to mitigate climate change and measures to facilitate adequate adaptation to climate change . . .”* . Nowhere are binding deadlines imposed to develop such adaptation strategies. Several countries have already taken steps in the development and implementation of national adaptation strategies (*e.g.,* France, The Netherlands, the United Kingdom, Finland, Denmark, Spain) (ECCP, 2006). With respect to Belgium a National Climate Plan was developed in 2002, but only concerning emission reduction commitments under the Kyoto Protocol without mentioning of adaptation efforts (National Climate Plan, 2002). Under the regional structure of the Belgian Government, the Flemish Government also developed two Flemish Climate Policy Plans. One for the period 2002-2005, which only related to emission reduction (Vlaams Klimaatbeleidplan, 2002-2005), and one for the period 2006-2012. The latter also deals with adaptation. It provides the future assessment of the effects of climate change for several sectors including agriculture, fisheries, forestry and tourism, and stated that a cost-effective Flemish Adaptation Plan will be developed, that will seek to strike a balance between minimizing the possible risks of climate and its impact on the socio-economic development (Vlaams Klimaatbeleidplan, 2006-2012).

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[2] UNFCCC, Decision 2/CP.11 in FCCC/CP/2005/5/Add.1, 30 March 2006.

[3] UNFCCC, Decision 1/CP.1 in FCCC/CP/2007/6./Add.1, 3-15 December 2007.

[4] Kyoto Protocol to the United Nations Framework Convention on Climate Change, United Nations, 11 December 1997, *B.S.* 26 September 2002.

Also within the European Union (EU), the Assessment Reports of the IPCC led, although stretched over a long period of time, to the adoption of the White Paper on adaptation (2009). The IPCC is mainly engaged in the assessment of the impacts and vulnerabilities of climate change and proposes adaptation strategies for different sectors. In this way the IPCC provides states and international organizations with a sound scientific basis for the development of an effective adaptation strategy. The first step in addressing climate change adaptation issues, within the EU, was the development of the Green Paper on adaptation by the European Commission.[5] The Green Paper was mainly a discussion paper an initiated a debate about adaptation within the EU. The White Paper provides a framework for future development of an EU adaptation strategy, as it stands this would be ready by 2013, and highlights the areas to focus on within this development (*e.g.*, increasing the understanding of climate change and possible adaptation measures and how adaptation can be embedded in key EU policies). The objective of the White Paper is to improve the EU's resilience to deal with the impact of climate change. Impacts of climate change will vary by region, with coastal and mountain areas and flood plains particularly vulnerable. For this reason most adaptation measures will need to be carried out nationally or regionally. The role of the European Union will be to support these efforts through an integrated and coordinated approach, particularly in cross-border issues and policies which are highly integrated at EU level. For this reason the White Paper calls on member states to take action to cope with climate change and to cooperate and share information on adaptation strategies.

With regard to the resilience of coastal and marine areas the White Paper states that climate change policy must properly be integrated in the implementation of the Marine Strategy Framework Directive[6]. The Marine Strategy Framework directive requires the achievement of good environmental status of the EU's marine waters by 2020. Furthermore, climate change adaptation also must be included in the Integrated Coastal Zone Management (ICZM) Recommendation[7] and in the Roadmap for Maritime Spatial Planning[8]. In the light of the fact that climate change will put additional pressure on European fisheries, the future reformed Common Fisheries Policy needs to take into account climate change with a view to ensuring long-term sustainability.[9]

The Commission has also prepared three discussion papers on water, coasts and marine, agricultural and health issues based on the framework set out in the White Paper. Regarding to this research the working document on climate change and water, coast and marine issues[10] is of interest. The working document defines several key impacts on water and coastal and marine areas (*e.g.*, changes in the natural environment, rising pressure on marine ecosystems and biodiversity, sea-level rise and ocean acidification will affect fisheries, aquaculture, wetlands and estuaries, increasing risk of infrastructure damage, coastal tourism will be affected by coastal erosion and changes in the marine environment and marine water quality). The working document highlights that all these impacts are enough reasons to develop a clear adaptation strategy, although further research is still needed in order to ensure that proper decisions on adaptation can be taken. The approach that the EU is pursuing is an integrated approach to both water management and to the management of marine and coastal zones, including

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[5] COM (2007) 354 final, Green Paper from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions: Adapting to climate change in Europe – options for EU action.

[6] Dir. 2008/56 (2008) OJ L164/19, The European Parliament and the Council establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

[7] Recommendation 2002/41(2002) OJ L148/24, Recommendation of the European Parliament and of the Council concerning the implementation of Integrated Coastal Zone Management in Europe.

[8] COM (2008) 791 final, Communication from the Commission: Roadmap for Maritime Spatial Planning: Achieving Common Principles in the EU.

[9] COM (2009) 147 final, White Paper: Adapting to climate change: Towards a European framework for action.

[10] SEC (2009) 386/2, Commission Staff Working Document accompanying the White Paper Adapting to climate change: Towards a European framework for action, Climate change and Water, Coasts and Marine Issues.

measures to mainstream adaptation into sectoral policies. Adaptation efforts need to be integrated into the implementation of existing EU water legislation and marine and coastal zone legislation and policies, such as the Water Framework Directive[11], the Flood Directive[12], the Marine Strategy Framework Directive[13] and in the Integrated Coastal Zone Management.

[11] Dir. 2000/60 (2008) OJ L327/1, The European Parliament and the Council establishing a framework for Community action in the field of water policy (Water Framework Directive).

[12] Dir. 2007/60 (2007) OJ L288/27 The European Parliament and the Council, on the assessment and management of flood risk (Flood directive).

[13] Dir. 2008/56 (2008) OJ L164/19, The European Parliament and the Council establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive).

7 Preliminary conclusions and recommendations

A first step has been made in the identification of the primary impacts. A literature study clearly shows that large uncertainties still exist on the primary impacts. Furthermore, large regional differences can exist. On the effect of the climate change on the intensity and frequency of severe storms, *e.g.*, different contradictory conclusions can be found in literature. Based on the literature study, three different scenarios were presented, including an improbable 'worst case' scenario, which can be used to account for the uncertainty.

Statistical analysis was used to evaluate in detail the sea level rise at the Belgian coast (Oostende). Data from the Hydro Meteo System, together with data from the PSMSL were collected. The different water levels (hourly, yearly, high and low waters) were reduced to the same reference level, and their quality was checked. Using the linear trend model, a sea level rise of 1.67 mm/year was calculated for the period 1927-2006. Other models (piece-wise linear, 2nd and 3rd order) were used as well, which suggest that the present SLR lies close to 4.4 mm yr^{-1}. The statistical analysis of the waves and the wind speeds showed decadal variability, related to the NAO. The long term trend and the linear regressions give some indication of a small decrease in significant wave height and wind speed over the Belgian coastal waters. For the maximum wave height and wind speed, the conclusions are less clear. Furthermore, a shift in wind direction to southwesterly winds was observed. Finally, the statistical analysis of sea surface temperature data indicated a clear increase: the highest increase was found in the central North Sea with an increase of about 0.05 °C yr^{-1}.

Moreover, different numerical models are being used to simulate the current situation and to assess the changes under the influence of the changes as described in the scenarios, *e.g.,* sea level rise or increased wind speed. From some preliminar tests, it can be concluded that a sea level rise of 2 m and an increase in wind speed of 8 % by 2100 (WCS 2100), can have some important effects, *e.g.,* the maximum currents decrease with 10 % in the Westerschelde mouth and increase in the region between Nieuwpoort and Zeebrugge.

Concerning the coastal flooding, it has been showed that a wide range of direct and indirect secondary effects of climate change related to coastal flooding can be identified. Further it is clear that the flood risk calculations are an excellent tool to assess the impact of the most important secondary effects of climate change (damages and victims). From the calculations, one can conclude that the weakest points in the natural defence along the Belgian coastline are located at the centres of Mariakerke, Oostende and Wenduine. Flooding risks are highest at built-up areas. First, the natural sea defence is lowered for the construction of buildings and roads. Second, the damage costs are higher due to the concentration of properties.

The most important primary effects of climate change that increase flood risks are sea level rise and increased storminess (higher wind speed and wave conditions). When taking into account the effects of climate change, at several locations along the Belgian coastline the height of the first defence is lower than the storm surge level of the extreme worst credible storm. The only zones where no overflow or breach occurs are those places where the original sea defence (the dunes) remained intact and have sufficient width.

Sea fisheries are an important activity for the coastal community of Flanders from a socio-cultural-economic point of view (Tessens and Velghe, 2006; Departement Landbouw en Visserij, 2007; SDVO, 2008; Demeyere, 2003). The strong specialization of the Belgian fleet with regard to fishing method (93 % beam trawlers) and target species (mainly flatfish) (Tessens and Velghe, 2008a) makes the Belgian fisheries sector rather vulnerable to these continuously changing circumstances. Rising fuel prices, declining fish stocks, fluctuating fish prices, a global financial crisis and various European and national regulations threaten the viability of the sector. Recently the sector is faced with yet another factor which contributes to the growing uncertainty: climate change (Brander, 2006; 2007; Philippart *et al*., 2007). Climate change will most probably impose additional pressure on the sea fishery, but may also offer opportunities.

There are strong indications that the ecosystem in general and the (commercial) fish stocks especially were, are and will be affected by climate change (Brander, 2007; Cook and Heath, 2005; ICES, 2008c; Philippart *et al*., 2007; Tulp *et al.*, 2006). The spatial distribution and/or recruitment of species important for the Belgian fisheries like sole (Rijnsdorp, 2008), plaice (Perry *et al.*, 2005; van Keeken *et al.*, 2007) and cod (ICES, 2002) were already affected by climate change. More southern commercial species, like red mullet and John Dory, which are currently not important for Belgian fisheries but have a high economic value and are still quota free species, are likely to increase their northerly presence in response to climatic warming (Engelhard *et al*., 2008b) Further temperature rises are likely to have profound impacts on commercial fisheries through continued shifts in distribution and alterations in community interaction (ICES, 2008a; Perry *et al*., 2005).

The conclusions of the workshop "Crisis in de Visserij: Keert klimaat het tij?" (Tuesday 9 December 2008, ILVO-fisheries, Oostende, Belgium) confirmed the findings of the work already conducted within the framework of the CLIMAR-project:

- The complexity of the Belgian sea fisheries sector and the ecosystem hamper the assessment of the impacts of climate change and the development of adaptation strategies, especially on the long-term.
- The Belgian fisheries fleet has a future, yet diversification and reengineering is needed.
- The ecological, economical and social aspects are equally important for the development of the sea fisheries into a sustainable activity.

The adaptation strategies which are under development should allow the fisheries sector to adapt effectively in order to mitigate the possible negative effects of climate change and to make use optimal of the opportunities created by climate change.

8 Prospects and planning of phase 2

The detailed description of the tasks for the year 3 and year 4 of the CLIMAR project are the following:

Work Package 1: Definition and modelling of climate change induced primary impacts at the North Sea scale

1.1 Hydraulic impacts - Change of hydrodynamic climate

The effect of sea level rise and change in storminess on the hydrodynamic climate will be further determined. For each of the scenarios, set up in the first phase of the project, the state-of-the-art hydrodynamic and wave models, implemented for the Belgian Continental Shelf will be used to predict the currents, water elevation and waves. The results of these simulations will be compared with the present situation. During the analysis of the results, main emphasis will be on the determination of the increased risk for flooding and the increased wave attack on the beaches.

For the calculation of the currents and the water elevations, the state-of-the-art three-dimensional operational hydrodynamic model mu-OPTOS (Luyten *et al.*, 1999) will be used. This model was developed in the framework of the European projects PROFILE, NOMADS and COHERENS. The model calculates the currents and water elevations on the Belgian Continental Shelf on a geographical grid with a resolution of about 750 m x 750 m. Over the depth, 20 σ-layers are used. The model is coupled with a three-dimensional model for the North Sea and a two-dimensional model for the North-West European Continental Shelf to calculate the boundary conditions.

For the calculation of the increase of waves, due to the sea level rise (less bottom friction) and increased wind speed, the SWAN model (Booij *et al.*, 1999; Ris, 1997) has been implemented to the same geographical grid in the first phase of the project. The SWAN model is a state-of-the-art third generation wave model, that calculates the full wave spectrum, taking into account the generation of waves, the wave propagation, the loss of wave energy, by breaking, white-capping or bottom friction, and non-linear interactions. The boundary conditions of the SWAN model can be provided by the operational mu-WAVE model (Van den Eynde, 1992) that is running for the North Sea and the Southern Bight.

1.2 Impacts on erosion and sedimentation

The changes in hydrodynamic climate, could also alter the erosion and deposition on the Belgian Continental Shelf. In the framework of the MAREBASSE project (Van Lancker *et al.*, 2005) a first attempt was made to define erosion and sedimentation patterns on the Belgian Continental Shelf by applying two different sediment transport models: a model for the transport of mud MU-STM (Fettweis and Van den Eynde, 2003) and a model for the transport of sand MU-SEDIM (Van den Eynde *et al.*, 2006). These models will be used in the present project to investigate the changes in erosion and sedimentation patterns for the different scenarios. More especially the increase in siltation of the fair channels and sea ports, will be studied. The main goal of this task is to make a first order estimate of these effects, which can be used as an input for calculating possible socio-economic applications. When more reliable estimates and tools could become available in the framework of the QUEST4D project, these results could be used of course by the current project.

Work Package 3: General identification of adaptation measures

Up to now different adaptation measures have been identified according to a common typology. These adaptation measures will further be described in detail making use of an Adaptation Measure Fact Sheet.

The most suitable adaptation measures will depend on the nature of the risks and the attitude to the climate risk. The effect (risk reduction) of each measure is the key parameter. This will be investigated based on a multi-criteria analysis, taking into account the possible side-effects and interrelationships of adaptation and the natural adaptive capacity of the ecosystem. The goal is to find no-regret adaptation options and win-win options, based on the principles of sustainability.

3.1 General identification of adaptation strategies

As the general concept for development for adaptation scenarios has been worked out, specific adaptation scenarios will be worked out for the different marine activities in the Belgian part of the North Sea based on the identified secondary impacts (see WP 2.1) and the identified adaptation measures. Besides the case-studies on coastal protection and fisheries (see further), adaptation scenarios will be worked out for the tourism sector. An iterative procedure will be followed to counteract conflicts between sectors, generate win-wins and develop an integrated adaptation approach. This will enhance the logical development of adaptive strategies, that will be evaluated in the 2nd part of this project (WP 4).

3.2 Adaptation scenarios against coastal flooding

As a case-study, the formulation of alternative coastal protection strategies as adaptation to climate change impacts will be established. Coastal protection strategies will be established based on 1) alternative strategies that have been studied for the neighbouring countries bordering the southern North Sea, especially the results of the European projects SAFECOAST and CHAIN OF SAFETY and the results of the Second Delta Commission in the Netherlands, 2) alternative coastlines that differ from the present “hold the line” policy but that however have to be kept in morphological equilibrium, 3) the outcome of the planned CLIMAR workshop on 4/12/2008 where win-win solutions will be sought with other sectors active in the Belgian coastal zone. In phase 2 of the project these alternative coastal protection strategies will then be evaluated using the same flood risk calculations as for the present coastal protection strategy.

3.3 Adaptation scenarios for the fisheries sector

The different indicators, elements at risk, vulnerability and possible adaptation for each secondary impact will be further identified. The information on alternative fishing methods will be compiled and the most relevant external factors will be selected. Further, the scenarios for the secondary impacts relevant for the fisheries sector, based on the basis scenarios, climate scenarios, deduced/modelled scenarios for the primary and direct linked effects agreed on by all partners, will be developed. The measures will be identified and the possible adaptation strategies will be compiled. Remark that a PhD on “Development and evaluation of long-term adaptation strategies for the Belgian sea fisheries sector” was started end 2008 (see 9.3 Other activities’ for details).

Work Package 4: Evaluation of adaptation scenarios

It is clear that although the main work on the development and selection of the different adaptation scenarios has been executed in the first phase of the project, the evaluation of these adaptation scenarios will lead to possible changes or extensions in the defined scenarios, or to the selection of new adaptation scenarios. The clear division in WP3 and WP4 is somehow administrative and the execution of the two work packages are inherently linked.

4.1 Coastal flooding and related activities

The risk reducing effect of the different possible structural and non-structural adaptation measures will be quantified by coastal flooding risk calculations using the Flemish methodology which is being established by Flanders Hydraulics Research within the framework of a European project called SAFECOAST. Apart from its functionality of reducing coastal flooding risks, the possible adaptation strategies will be evaluated with respect to their effects on all other sectors. Different evaluation tools will be tested, such as multi criteria analysis and societal cost-effectiveness analysis.

4.2 Fisheries sector

In order to evaluate the different (pro-active) adaptation strategies elaborated in the first phase of the project, ILVO-fisheries will, in accordance with the other partners, select appropriate evaluation parameters and develop an 'evaluation framework'. The combination of the selected parameters should facilitate the selection of those adaptation strategies aiming at the development of the Belgian fishery into an innovative, flexible and durable activity; able to cope with changing circumstances, including climate changes. This multi-criteria approach is reflected in the long-term strategy for the Belgian fleet currently being developed at ILVO-fisheries; and takes in account economical, ecological and technological criteria. The strategy outlines a new direction and forms a guideline towards the establishment of an optimal fleet structure in terms of type of fishing vessel and fishing methods. Although the developed "framework" will be sector specific, it will (partially) serve as a blueprint for the extrapolation towards other marine activities.

4.3 Evaluation framework for adaptation strategies

A climate adaptation strategy represents a combination of measures and options chosen to meet a particular risk (European Environment Agency, 2004). The strategy should increase the robustness of long term (infrastructure) investments, enhance the adaptability of vulnerable natural systems, improve societal awareness and preparedness, increase the flexibility of vulnerable marine activities (*e.g.*, ease of change of activities or locations). The success of the full strategy depends on numerous factors such as the effectiveness of the measures, the acceptance of the introduction, the potential for benefits that outweigh the costs, the consistency of the measures with other sectoral initiatives, etc.

In order to stimulate the abovementioned preconditions for the sectoral adaptation strategies, an evaluation framework will be developed that can assess the value of the scenarios for each specific marine sector. The evaluation tool is based on the principles of sustainable development and scores both economical, ecological and social merits and damages of the adaptation strategy. Hence the adaptation strategies have to undergo a sustainability test. Full use will be made of the case-studies for "coastal flooding" and for the "fisheries sector", as well as – from a methodological point of view – the elaboration of an assessment framework during the ADAPT project.

To develop this framework or evaluation tool, all technical possibilities will be explored (Toth, 2000). Integrated assessment should combine, interpret and communicate knowledge from different disciplines. Generally, current assessment techniques only fulfil part of this need. Furthermore when considering climate change impact and reduction, less attention has gone to assessing adaptive strategies while focusing on prevention strategies. Among others, consideration will go to:

- multi-criteria analysis - using indicators of impact and indicators for efficiency of measures;
- (social) cost-benefit analysis (valuing all costs and benefits over time on the base of "willingness to pay";
- cost-effectiveness analysis (taken a predetermined objective and seeking a way to accomplish it "as inexpensively as possible");
- "policy translation approaches" (trying to translate the "technical story" into a story understandable for policy makers);
- probability and statistics;
- uncertainly analysis and data gaps;
- decision periods and relation with prevention strategies;

It can already be stated that probably, the “ideal technique” for a specific sector will be, either a combination of techniques and/or different for each sector. Hence the evaluation framework will have to incorporate flexibility and consist of different modelling techniques.

Much will be learnt from the practical case-studies, mentioned above. They should guarantee the applicability of the “framework” and stimulate the extrapolation towards other marine activities. Furthermore, it is clear that the development of the “evaluation framework” will be carried out in close collaboration with the “policy and legal evaluation”, which will be explored in the next chapter.

4.4 Policy and legal evaluation of adaptive strategies

The legal approach for this research is two folded. On the one hand, there is research into the legal evaluation of adaptation measures and on the other hand, there is research into the legal evaluation of the adaptive strategies. In order to be able to evaluate the proposed adaptation measures and adaptive strategies a list of the relevant policies and legislation with implications for adaptation measures and strategies has to be made. Since nowadays environmental legislation is to a large extent determined by international and European (soft and hard) law, which is, in Belgium, transposed and implemented at the regional level, although the federal government retains important prerogatives. Furthermore adaptation measures against climate change are rarely “stand-alone” environmental measures and therefore the involvement of several other legislation and policy sectors on different levels is often required. In this respect the relevant legislation must be assimilated from a wide variety of legal categories including European and International law and additional national legislation and policies. The list of the relevant legislation will ensure that a legal framework can be established for the proposed adaptation measures. It will be investigated to what extent use has to be made of existing tools such as Environmental Impact Assessment (EIA).

Starting from the total climate change policy (UNFCCC, IPCC, EU and further implementation on a national level), the international and national legislative framework (including issues regarding ICZM) as well as strategic documents formulated by all socio-economic marine related sectors, but also using results from the global evaluation tool and the case-studies, the adaptive strategies against secondary climate change impacts will be evaluated. It will be investigated to what extent use can be made of existing tools such as Regulatory Impact Assessment (RIA), Strategic Environmental Assessment (SEA) and Sustainability Impact Assessment (SIA). Regarding the latter, use will be made of the results of the Federal Science Policy research Project “Methodology and feasibility of SIA. Case: Federal Policy-making Processes” which ended in February 2006. To enable a thorough evaluation of the adaptive strategies, the international policy on adaptation must be examined as well as the international legislation, mainly EU legislation which can influence the development of an adaptation strategy (*e.g.,* Marine Strategy Framework and Flood Directive). It is also useful to look at the development of adaptation strategies in other northwest European countries (UK, Ireland, The Netherlands and France) who face similar climate change impacts. Moreover, there will be an investigation into how these other countries already implement adaptive strategies in their policies and legal instruments, which adaptation measures they propose and assess the advantages and disadvantages. Recommendations will be formulated on the effect of the adaptive strategy, the embedding in the global climate change policy as well as the practical integration of this strategy in the current policy and legislative framework.

4.5. Recommendations

Based on both case studies on the one hand and the parallel integrated assessment and policy & legal evaluation on the other hand, recommendations will be formulated towards a Belgian future North Sea policy and its different socio-economical activities. This valuable output for a Belgian marine climate change policy will consist both of practical tools (modelling, assessment) as well as quantified results and applications.

Work Package 5: Coordination and valorisation activities

5.1 Coordination

The administrative and financial aspects of the project will be followed up by the project co-ordinator.

The project website http://www.arcadisbelgium.be/climar was set up in the first phase of the project to describe the content and status of the project. The website will be maintained and continuously updated during the phase 2 of the project, with an intranet (for project management and information exchange within the project) and access for all parties (containing final reports, modelling results, presentation, background documents, communication possibility, etc.).

5.2 Workshop

At the end of the project, a workshop will be organised, where the final results of the project will be presented. This workshop will be aimed at a large group of officials, scientists and stakeholders with an interest in marine activities and/or climate change. The focus of the workshop will be the policy translation of the scientific results; hence the core group aimed at will be the policy makers. The subcontracter VLIZ will be responsible for the practical organisation of the workshop.

5.3 Follow up committee and internal meetings

At least two times a year, partner meetings will be organised. These will include an overview of the state of the project and a control of the time schedule. This will however not preclude the organisation of ad-hoc meetings whenever necessary.

Furthermore, twice a year meetings with the user committee will be organised. During these meetings the state of the project will be reported. Interaction and discussion with the end users will be promoted.

9 Publications/valorisation

9.1 Publications and reports

De Smet, L. and R. De Sutter, 2008. Development of a management tool for the equal evaluation of economic, social and ecological effects of adaptation scenarios for attenuating the effect of climate change induced. In: Proceedings of the 11th International Specialised Conference on Watershed and river basin managemen, Budapest, Hungary.

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9.2 Other activities

As the Belgian ambassador for the socio-economic aspects of ICZM, Annemie Volckaert has presented the CLIMAR project at the:

- International ENCORA 1st Thematic Network Conference (Venice, 13 March 2007)
- National BENCORE conference (Brussels, 26 April 2007)

Katrien Van der Biest presented the CLIMAR project at the:

- National Second BENCORE conference (Leuven, 30 May 2008)
- National Water en Klimaatverandering conference (Antwerpen, 15 October 2008)
- International LITTORAL conference (Venice, 26 November 2008)
- Tweetalige Conferentie Klimaatverandering : wat zijn de effecten op grensoverschrijdende gebieden? (Duinkerke, 13 mei 2009)

Els Vanderperren presented the CLIMAR-project (case-study fisheries) at the

- Congress ‘Climate Change: Global Risks, Challenges and decisions’, session N° 35 ‘Adapting Coastal Zone and Marine Recourses to Climate Change’ (Copenhagen, Denmark, 10-12 March 2009)

Renaat De Sutter, with contributions of Willems P. (CCI-HYDR project): Klimaatsverandering en het watersysteem: gevolgen in België. Presented at the B-IWA (Belgian International Water Assocation) Workshop, 4th June 07, Brussels.

Dries Van den Eynde presented the CLIMAR project at the SEAMOCS Conference, Effects of climate change: coastal systems, policy implications, and the role of statistics, Sliema, Malta, 18-30 March 2009.

José Ozer gave a presentation “On the variations in MSL and storminess along the Belgian coast (southern North Sea): some observational and model results” at the Workshop on Flood Vulnerability and Flood Protection in Tidal and Non-Tidal Regimes: North and Baltic Seas, 27–29 April, 2009, Delft, The Netherlands.

Toon Verwaest presented the CLIMAR project at Réunion d'information sur l'évolution des risques naturels littoraux liés au changement climatique: Les futures risques littoraux en Belgique, et comment les gérer?. 16 July 2008, Gravelines (Nord-Pas-de-Calais)

Patrick Willems, with contributions of T. Verwaest, P. Baguis,, A. Ducharme, & P. Viennot: Impact van klimaatverandering op hydrologische en hydraulische extremen in de Schelde- en Seine-rivierbekkens en langs de Noordzeekust, Presented at Congres Water en Klimaatverandering, 14 en 15 oktober 2008. Abstracts van lezingen en posters. pp. 5-12.

9.3 Education

- Stijn Vandousselaere, 2007-2008. Climate Change in Belgian harbours: problem or opportunity. Master thesis, University Gent, Engineering Faculty. Promotor prof.dr.ir. Renaat De Sutter.
- De Sutter R., contribution to the presentation of Eric Schellekens, Arcadis, on the KVIV (Royal Flemish Engineering Society) conference, with topic "Climate Change and Flooding", WLH Borgerhout, 19 February 2008.
- Within the framework of CLIMAR Els Vanderperren, who's responsible for the daily work on the case-study fisheries, started with a PhD on the "Development and evaluation of long-term adaptation strategies for the Belgian sea fisheries sector". Promoters are prof. dr .ir. Renaat De Sutter and George Allaert from the University of Gent, - Department of Civil Engineering (IR15) - Integrated water management & Environmental policy and partner in CLIMAR. Co-promoter is Dr. Ir. Hans Polet from ILVO-Fisheries and involved in CLIMAR as well. This PhD aims at developing/modelling fleet performance and structure, taking into account the current situation and including the associated parameters and drivers important for the fisheries sector. The first driver which will be detailed and implemented will be 'climate change'. This model will consequently be used to evaluate the developed adaptation strategies and formulate recommendations. It is apparent that the work performed within the framework of this PhD will feed into the different work packages of the CLIMAR project and *vice versa*.

9.4 Support to decision

Renaat De Sutter will contribute to the MIRA (Milieu-Rapportage Flanders) Scenario development (period July 2008 – April 2009) for the theme "climate change", more specifically by reporting about the state of progress of the Climar project. Jeroen Brouwers, VMM-Mira project leader, is also member of the follow-up committee of CLIMAR.

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