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Threat of sea level rise: Costs and benefits of adaptation in European Union coastal countries.

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ABSTRACT

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The unavoidable physical consequences of increased sea-level due to global warming and the large concentration of socio-economic and natural assets at the coast raise much concern about possible economic damages. When discussing climate related threats with decision makers, cost-benefit analyses that support decisions are often demanded. The Dynamical Interactive Vulnerability Tool (DIVA) allows calculating the benefits of a normative coastal protection target versus a business as usual (BAU) scenario for the European Union (EU) coastal states. Results show that for most EU coastal countries long-term economic benefits are expected for a well-defined adaptation strategy during the second half of the 21st century. By 2100, about 200 bio $US are expected to be avoided if all EU coastal countries target the 100 year coastal protection goal. The situation is not equal for all countries, for some like Netherlands and Irish Republic large benefits up to 5.5% of the 2007 GDP are expected, while for countries like Estonia and Cyprus the adaptation level chosen proved to be too costly when compared with the impact costs of a BAU scenario.

ADITIONAL INDEX WORDS: *Vulnerability, Avoided Impacts, Cumulative Costs, Decision Making*

INTRODUCTION

Sea-level rise is one of the most important impacts of Climate Change (Jeffrey, 2007) and the high concentration of valuable socio-economic and natural assets on coastal zones raises much concern about possible economic damages and ecological consequences.

Today, coastal zones are negatively affected by a number of factors such as significant urbanizing trends (Nicholls, 2002) and high population density about three times higher than global average (Small and Nicholls, 2003). McGranahan (2007) estimated that globally 10% of the world's population and 13% of the urban dwellers are located within coastal areas below 10 meters elevation. This exacerbates socio-economic vulnerability and constrains the adaptation capacity of coastal systems that face changes on future sea-level (cf. (Ericson and Vörösmarty et al., 2006)).

Despite being said that coasts are facing the prospect of a global sea-level rise, it does not mean that sea-level is increasing equally around the world. Local change in sea level at any coastal location depends on the sum of global, regional and local factors and is termed relative sea-level change (Nicholls, 2002). Over the main time scale of human concerns, relative sea-level is the sum of three components: global mean sea-level rise, regional meteo-oceanographic factors and vertical land movement (Church and Gregory et al., 2001). As long as global sea-level trend is small, regional processes can prevail and significantly influence relative sea-level rise (e.g. land downlift by gas and oil exploitation), nevertheless, a more pronounced global sea-level rise is likely to overcome these local effects.

In the 20th and 21st century, global mean sea-level rise is primarily caused by thermal expansion of the upper ocean layer and melting of small ice caps due to human induced global warming (Church and Gregory et al., 2001). Despite of this known fact, understanding global sea-level change is a difficult physical problem (Rahmstorf, 2007) and much scientific debate was raised when the IPCC 4th Assessment Report pointed out, depending on the socio-economic scenario, a rise of sea level between 0.18 an 0.59 meters by 2100 when compared to the 1980-1999 level. These numbers are believed to be underestimated and a global mean sea-level rise of over 1 meter by 2100 for strong warming scenarios cannot be ruled out (Rahmstorf, 2007). In addition, recent alarming messages were reported, i.e. global warming is accelerating and Greenland ice sheet is melting twice faster than assumed by science. In particular these melting glaciers will have an important impact on future sea level. Besides the dispute about the exact values of future sea-level rise, it is certain, due to physical effects, that even if global warming is stabilized today global mean sea-level will continue to rise through the 21st century due to oceanic thermal inertia (Wigley, 2005).

Although a global mean sea-level rise will very likely have a negative impact on low lying coastal areas, the most destructive effects to coastal zones originate from the occurrence of storm surges. Coastal zones are facing the prospect of changing storm statistics due to anthropogenic climate change, with mean sea-level rise adding to the height of the storm surge (Woth and

WEISSE et al., 2006). If the frequency of extreme storm surges events becomes shorter several socio-economic issues arise. The continued repair of damaged human infrastructures may start to become economically unsustainable, evacuating persons during storm surges events may also become more frequent and increased land lost will threaten the already stressed ecological ecosystems.

In the European Union (EU) coastal countries, human population and natural systems will become more vulnerable due to an increase of physical exposure to sea-level rise. Although these countries have the capacity to adapt, at least in terms of their financial strength, it is not certain that adaptation measures regarding sea-level rise are easily implemented on future coastal planning strategies. The endless debate on future sea-level rise projections, low risk perception (cf. (EISENACK and TEKKEN et al., 2007)) due to the long time scale of the phenomenon and the fact that decisions at the coasts have long term implications are sources of uncertainty to decisions makers and may induce delay in adaptation actions. On the other hand, without adaptation, the high-end sea-level rise scenarios, combined with other climate changes (e.g., increased storm intensity) will likely turn some islands and low-lying areas unviable by 2100 (NICHOLLS and WONG et al., 2007).

When discussing climate related threats with decision makers, cost-benefit analyses are often demanded in order to support decisions. This demand is understandable, but not very realistic. Calculated numbers depend on a variety of assumptions, e.g. on the economic and demographic developments or on mankind's decisions regarding climate protection. Since nobody can forecast these developments, vulnerability assessments are a useful tool to close gaps between impact analysis and necessary adaptation strategies by identifying the hotspots for action. Experiences show that this can help decision makers to implement strategic actions (KROPP and BLOCK et al., 2006). The advantage is that vulnerability analyses make situations comparable and allow to assess where future action is most urgently needed.

Consequently, we use the Dynamical Interactive Vulnerability (DIVA) Tool (HINKEL and KLEIN, 2003) to assess damage and adaptation costs for the European countries for two different scenarios: A consequent coastal adaptation under a predefined protection level and a non-adaptation scenario, i.e. the current coastal situation is only preserved and no further coastal protection policies take place.

METHODS

The DIVA tool

The Dynamical Interactive Vulnerability Tool (DIVA) is a geographic information system consisting of several modules. Globally it comprises 12148 coastal segments with similar physical characteristics (cf. (MCFADDEN and NICHOLLS et al., 2007)). For each segment DIVA provides a multitude of parameters such as population density, wetland area, frequency and height of storm surges and area flooded.

The parameters are used as input for the several modules of DIVA which represent specific knowledge domains or scientific disciplines, e.g.: the flooding module calculates the flooding of low-lying coastal areas due to the combined effects of storm surges and sea-level rise. The costs of sea-level rise impacts on certain sectors, e.g. agriculture or housing, are estimated by a costing module (cf. e.g. (TOL, 1995)). For a more detailed description of the modules please see (HINKEL and KLEIN, 2004).

Table 1: Impact and adaptation cost categories provided by the DIVA tool

Impact costs	Costs of adaptation
Sea flood costs	Sea dike costs
River flood costs	River dike costs
Salinity intrusion costs	Beach nourishment costs
Land loss costs	Wetland nourishment costs
Human migration (due to land loss) costs	Tidal basin nourishment costs

Besides some necessary criticism regarding the DIVA tool, e.g. with regard to the internal economic valuing or to its coarseness, it is a useful instrument to provide a comparable overview. Thus, calculations are based on pre-selected assumptions of a climate forcing scenario and coastal protection targets (which are normally policy goals), to estimate costs for adaptation and benefits for different categories (Table 1).

Scenario assumptions

Due to the fact that sea-level rise is possibly underestimated we use the A2 forcing for calculation of sea-level rise. For the EU coastal countries this translates into a range of sea-level increase between approximately 50 cm for Spain and 1 meter for the Netherlands.

Damage and adaptation costs for the EU coastal countries were calculated using two different sets of adaptation options: a business as usual (BAU) scenario and an adaptation (ADP) scenario. For the BAU scenario, it was assumed that no adaptation would occur; this implies that no new dikes would be constructed and the existing coastal protection infrastructures will be maintained only. For the ADP scenario a minimum protection level of 100 years is assumed (as it is common in several European countries) meaning that that the coast should at least be protected against a 100 year flood event.

Costs and benefits of adaptation

For each EU coastal country, total costs (*Tc*) of sea-level rise for both scenarios are calculated according to the following equation:

$$Tc = (I + A)$$

I is the sum of sea flood, river flood, salinity intrusion, land loss and human migrations costs, while *A* is the sum of the costs for sea and river dike construction, beach, wetland and tidal nourishment.

Avoided impacts (*Ai*) are assessed using the expression:

$$Ai = (I_{BAU} - I_{ADP})$$

Where I_{BAU} and I_{ADP} are, respectively, the impact costs calculated in the BAU and ADP scenarios.

Costs of adaptation (Ac) are provided by the equation:

$$Ac = (A_{ADP} - M)$$

M refers to the costs of maintenance options taken forward in the BAU scenario. A_{ADP} represents the costs of adaptation in the ADP scenario, these include the construction of new dikes and further nourishment, the difference of these two costs (Ac) are therefore the adaptation costs.

Theoretic benefits of adaptation options to sea-level rise for a given EU coastal country (Tb) can be estimated by comparing the two previous cost categories:

$$Tb = Ai - Ac$$

If Tb is positive, it means that the avoided impact costs are higher than the costs necessary for adaptation. On the other hand, if Tb is negative, it means that the costs for achieving a 100 year coastal protection level are higher when compared with the costs of avoided impacts.

Total costs alone do not reflect the complete degree of a country's vulnerability. For example, countries facing the prospect of high economic losses might also have the economic strength to cope with such scenario. On the other hand, countries with comparatively lower projected costs might be unable to implement the costly adaptation measures and still face the economic losses of increased sea-level rise impacts. In other words, some measure of adaptive capacity should be included. It is therefore reasonable that all cost categories projected for the EU coastal countries are normalized to the country GDP (2007) (calculated in terms of Purchasing Power Parity (PPP$) extracted from the Central Intelligence Agency World Fact Book), providing an idea of the economic capacity of a country to deal with the rising costs of sea-level rise. This approach allows costs of sea-level rise impacts and adaptation for different countries to be inter-compared.

RESULTS

Total costs (Tc) regarding all EU coastal countries reveal that cumulative costs for the BAU and ADP scenario have a similar magnitude during the first half of the 21st century with costs for the ADP scenario ranking higher (Figure 1). Both scenarios show a steady and approximately linear rise of costs until 2050. From here on the curve representing costs related to the BAU scenario acquires an exponential shape overcoming the ADP scenario costs by 2075 remaining higher until the end of the century. By 2100, cumulative costs of adaptation and impacts in the EU coastal countries for the BAU scenario range up to 550 bio US$ wile expected costs for the ADP scenario are of about 350 bio US$. According to this, a total of 200 bio US$ can be avoided if all EU coastal countries engage on adaptation measures aiming for a 100 year protection level.

Nevertheless this does not imply that for all countries the benefits are only achievable beyond 2075. While for Finland the coastal protection falls below the 100 year target around 2075, for Germany this holds for 2050 and for Estonia already for 2015 implying that costs and benefits of coastal protection are very uneven distributed for the EU countries.

Most EU coastal countries will face higher total costs due to enhanced sea-level rise by 2100 following a BAU policy when

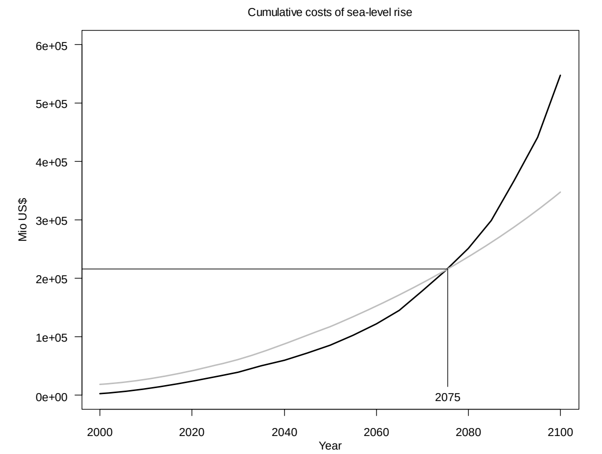

Figure 1. Cumulative total costs (Tc) of sea-level rise impacts for the EU coastal countries according to the BAU (black) and ADP (grey) scenarios

compared with the ADP scenario. Netherlands is by far the country facing the highest costs. With regard to the BAU scenario, nearly 25% of its 2007 GDP will be necessary for the next 100 years to cope mostly with impacts caused by increase sea-level and dike maintenance. Costs for Denmark, Belgium and Republic of Ireland are expected to stay below 10% while for the remaining EU coastal countries losses are not higher than 5% of the 2007 GDP.

Results for the avoided impacts (Ai) and adaptation costs (Ac) by 2100 reveal that most EU coastal countries are expected to avoid substantial economic losses (up to 5.6% of 2007 GDP) due to the implementation of adaptation measures (Figure 2). Republic of Ireland and Netherlands are the countries with higher avoided cumulative impact costs by 2100. Countries like Belgium, France, Portugal and Germany may achieve substantial reductions of sea-level rise impact costs with rather low costs on adaptation. For Portugal and Germany costs of adaptation are, respectively, only

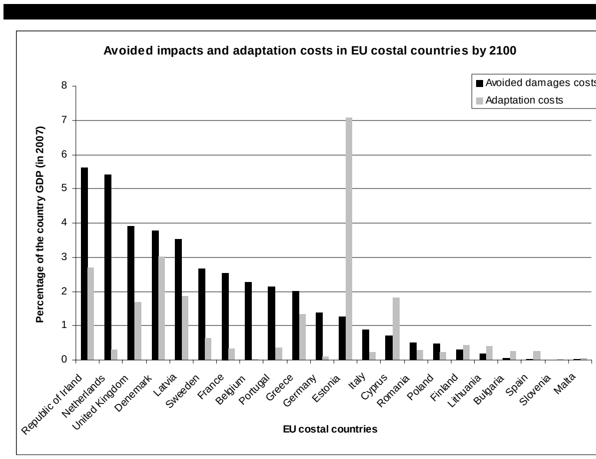

Figure 2. Avoided impact (Ai) and adaptation costs (Ac) of sea-sea-level rise in EU coastal countries by 2100

0.4 and 0.01% of the 2007 GDP. These values are six and fourteen times lower than costs of impacts by 2100. Such numbers show well the economic advantages in the long run of the normative decision for 100 year coastal protection for both countries.

Despite a large prevalence of lower costs for the ADP scenario across the EU coastal countries, there are some examples where higher costs for adaptation are expected. In other words, following the BAU strategy adopted in his paper could be economically more rational for countries like Estonia, Cyprus, Finland, Bulgaria, Spain, Lithuania, Slovenia and Malta. The case of Estonia is the most extreme one, with costs for adaptation that are about five times higher than the expected avoided impacts.

Its no surprise therefore that Estonia and Cyprus appear in Figure 3 as the EU coastal countries with no expected theoretic benefits (*Tb*) regarding the chosen adaptation level in this study. The losses for Estonia and Cyprus are of almost 6% and 1 % of their 2007 GDP respectively. Countries like Spain, Finland, Lithuania, Bulgaria, Slovenia and Malta also present economic losses due to the chosen adaptation options; nevertheless, these do not overcome 0.2% of the 2007 country GDP.

Netherlands leads the ranking of countries expecting economic benefits from adaptation to sea-level rise with a value of just over 5% of its 2007 GDP by 2100. With theoretic benefits up to almost 3%, Republic of Ireland is the second EU coastal country that has more to gain from the implementation of adaptation options. For the remaining EU coastal countries the theoretic benefits are below 2.2 % of its GDP by 2100.

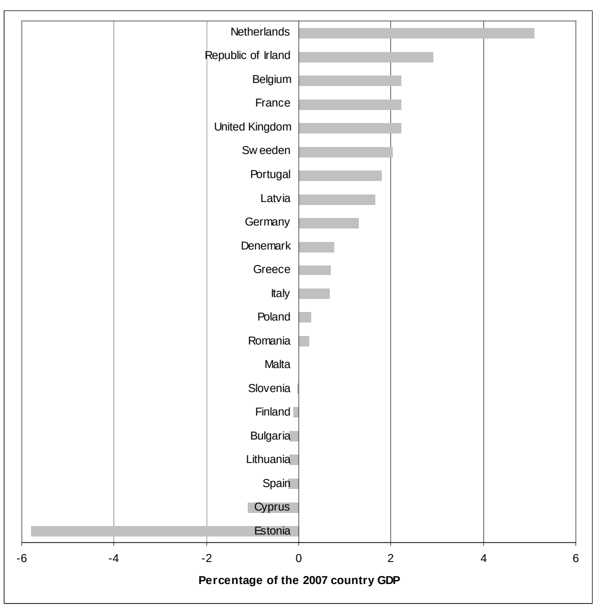

Figure 3. Theoretic benefits of adaptation for the EU coastal countries by 2100

DISCUSSION

For all European Union coastal nations we estimated the total costs of sea-level rise in case of a business as usual scenario and for a predefined adaptation scenario using the DIVA tool.

Results indicate that most EU costal countries are expected to benefit, in the long run, from predefined adaptation options to sea-level rise. Nevertheless, for some countries, achieving the predefined adaptation level assumed in this study revealed to be more costly than the costs of potential impacts in a BAU scenario.

For some countries the results were astonishing, e.g. for Estonia. At the first glance it is not easy to interpret why Estonia should benefit from a BAU strategy. In-depth analysis reveals that this behavior is consistent: Estonia currently has no or only few dikes. In this context a normative protection level like assumed in our analysis makes it necessary that large kick-off investments are taken forward in only a few years. In addition, it might be that these costs are higher today than in the future.

Among the countries that expect theoretic benefits, differences regarding the proportion of necessary costs with adaptation and avoided damages were found. For example, Portugal, Belgium and Greece present approximately the same level of avoided impact costs; nevertheless, the amount of GDP necessary for implementing the predefined adaptation options is considerably different. Belgium is expected to spend ten times less of its 2007 GDP than Portugal in order to obtain similar benefits on the long run, furthermore, the adaptation costs in Portugal are almost four times lower than the ones in Greece for the same adaptation level and identical avoided damage costs. This distinct behavior may be due to the combined effects of three factors: coastal length, amount of low lying areas and existing coastal defenses.

The relative small costal length of Belgium (65 Km) associated with the fact that about 60% of the coastline already has some form of coastal defence structure leads to considerable low amounts of adaptation costs. Despite this, Belgium accounts for a large extent of low lying coastal areas important for beach tourism and agriculture (ALLAERT, 1996). The avoided impacts are therefore potentially high. On the other hand, Portugal would have to invest in new infrastructures for coastal protection such as river and sea dikes; these are known to be costly, increasing the costs of adaption. Regarding Greece, the lengthy coast may be the main reason for considerably higher adaptation costs than in Portugal.

CONCLUSIONS

Results show that a costal adaptation strategy for 100 years like the one explored in this paper will provide economic benefits in the second half of the 21st century for almost all EU coastal countries. Considerable amounts of damages can be avoided by relative low investments on coastal adaptation for most EU coastal member states. Nonetheless, due to the fact that for adaptation and damage costs the assumptions are valid, DIVA tool provides comparable results for Europe's coastal countries.

Summing up, we feel that DIVA is a useful tool to support decision makers, although upgrades in terms of its spatial resolution, its dynamical implementation and its valuing modules would be useful. On the other hand, and according to the arguments provided in the introduction, absolute certainty about the future will not be possible. Given the complexity of the system and the inherent irresolvable uncertainty, it must be accepted that we have to deal with weak and soft prognoses, which are nevertheless often based on state of the art methodologies (KROPP and SCHEFFRAN, 2007).

So far the normative protection target can only be defined for a whole country, this implies that in its current form the DIVA tool can only provide costs on a high aggregated level and cannot distinguish which coastal regions of a given country expect higher costs. Here further improvements are possible. One the other hand, and despite of these limitations, further analyses show (e.g. for Singapore) that the economic effects estimated are in line to those estimated by econometric approaches (NG and MENDELSOHN, 2005)

DIVA results provide an indication on possible economic benefits of long term adaptation policies, an indication that future coastal policies should be anticipatory rather than reactive. Anticipatory decisions on adaptation options to sea-level rise, namely the construction of new infrastructures, need to be made in face of the large uncertainty about future climate scenarios. There is a need to think in a risk and uncertainty based manner rather than looking for deterministic solutions.

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REFERENCES

ALLAERT, G. (1996). The Belgian Coast: Signs of recent revival?, Faculty of Applied Science, Ghent University.

CHURCH, J. A., J. M. GREGORY, P. HUYBRECHTS, M. KUHUN, K. LAMBECK, M. T. NHUAN, D. QIN and P. L. WOODWORTH (2001). Changes in Sea Level. Climate Change 2001. Cambridge, Cambridge University Press.

EISENACK, K., V. TEKKEN and J. P. KROPP (2007). Stakeholders perception on climate change in the Baltics. Coastline Reports**:** 245-255.

ERICSON, J. P., C. J. VÖRÖSMARTY, S. L. DINGMAN and L. G. WARD (2006). "Effective sea-level rise and deltas: Causes of change and human dimension implications." Global and Planetary Change **50**: 63 – 82.

HINKEL, J. and R. J. T. KLEIN (2003). "DINAS-COASTS: Developing a Method and a Tool for Dynamic and Interactive Vulnerability Assessment " LOICZ Newsletter **No.27**: 1 - 4.

HINKEL, J. and R. J. T. KLEIN (2004). "DINAS-COAST: Developing a Method and a Tool for Dynamic and Interactive Vulnerability Assessment." DIVA tool documentation.

JEFFREY, A. M. (2007). "Episodic flooding and the cost of sea-level rise." Ecological Economics **63**: 149 - 159.

KROPP, J. P., A. BLOCK, F. REUSSWIG, K. ZICKFELD and H. J. SCHELLNHUBER (2006). "Semiquantitative Assessment of Regional Climate Vulnerability: The North-Rhine Westphalia Study." Climate Change **76**: 265 - 290.

KROPP, J. P. and J. SCHEFFRAN (2007). Advanced Methods for Risk Management and Decision Making in Sustainability Science. New York, Nova Science Publishers.

MCFADDEN, L., R. J. NICHOLLS, A. T. VAFEIDIS and R. S. J. TOL (2007). "A Methodology for Modeling Coastal Space for Global Assessment." Journal of Coastal Research **23**: 911 – 920.

MCGRANAHAN, G., D. BALK and B. ANDERSON (2007). "The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones." Environment and Urbanization **19**: 17 - 37.

NG, W.-S. and R. MENDELSOHN (2005). "The impact of sea level rise on Singapore." Environment and Development Economics **10**: 201 - 215.

NICHOLLS, R. J. (2002). Rising sea levels: potential impacts and responses. Global Environmental Change. R. E. HESTER. and R. M. HARRISON. Cambridge, Royal Society of Chemistry**:** 83 - 107.

NICHOLLS, R. J., P. P. WONG, V. R. BURKETT, J. O. CODIGNOTTO, J. E. HAY, R. F. MCLEAN, S. RAGOONEDEN and C. D. WOODROFFE (2007). Coastal systems and low-lying areas. Assessment Report of the Intergovernmental Panel on Climate Change. M. L. PARRY., O. F. CANZIANI., J. P. PALUTIKOF., P. J. LINDEN. and C. E. HANSON. Cambridge, Cambridge University Press**:** 315 - 356.

RAHMSTORF, S. (2007). "A Semi-Empirical Approach to Projecting Future Sea-Level Rise." Science **315**: 368 - 370.

SMALL, C. and R. J. NICHOLLS (2003). "A global analysis of human settlement in coastal zones." Journal of Coastal Research **19**: 584 - 599.

TOL, R. S. J. (1995). "The Damage Costs of Climate Change Toward More Comprehensive Calculations." Environmental and Resource Economics **5**: 353 - 374.

WIGLEY, T. M. L. (2005). "The Climate Change Commitment " Science **307**: 1766 - 1769.

WOTH, K., R. WEISSE and H. STORCH (2006). "Climate change and North Sea storm surge extremes: an ensemble study of storm surge extremes expected in a changed climate projected by four different regional climate models." Ocean Dynamics **56**: 3 - 15.