NATURAL **HAZARD RISK ASSESSMENTS** FOR **IMPROVING RESILIENCE** IN EUROPE

The ENHANCE project has received funding under the Seventh Framework Programme of the European Union under grant agreement No 308438

During the past decades, the frequency and economic damage of natural disasters has increased sizeably both worldwide (Munich Re, 2014) and in Europe. A number of major disasters took the stage in Europe, prompting high economic damage and losses, casualties and social disruptions. Examples are the 2010 eruptions of the Eyjafjallajökull volcano in Iceland; earthquakes in Italy in 2009 and 2012; droughts and forest fires in Portugal in 2012; heavy rainfall that caused record floods in Central Europe in 2013; and a hail storm that hit France, Belgium and Western Germany in 2014 and caused about €3.5 billion damages (Munich Re, 2015).

Natural disaster risks and losses in Europe are of high policy and citizen concern. Worse, they are expected to further rise as a result of projected demographic development and land use change, with expansion of residential and production activities in disaster-prone areas. Climate change has been demonstrated to have already increased the frequency and severity of certain extreme climate and weather related events, such as droughts, heat waves and heavy precipitation (IPCC, 2012; IPCC, 2014). These phenomena will further unfold as the human induced climate change will become more pronounced. Hence, it is imperative to take action on disaster risks to improve resilience of European societies to natural hazards.

Risk assessments for resilience

A variety of strategies can be designed to curtail disaster risks and improve resilience, including early warning systems, structural flood protection, ecosystem restoration to repair natural buffers, building code policies that limit property damage, and land use policies that steer development towards safe areas (IPCC, 2014). Financial and economic instruments have a potential to help incentivizing risk reduction and transfer, for example through innovative insurance schemes that shift residual and excessive risks to financial markets and hence limit the consequences for those affected (Botzen, 2013). Such strategies can be designed by public policy makers and private actors, single-handedly or, better, acting through a partnership. Scientists can help improving shared understanding and appreciation of risk as an important ingredient for designing effective and efficient risk management solutions. The importance of damage and loss assessment and accounting has been recognized in the zero draft of the post-2015 Framework for Disaster Risk Reduction[1] . The EU has taken up the task of improving records of disaster losses as the recent initiatives by the EU Directorate General Humanitarian Aid and Civil Protection and Joint Research Centre illustrate (EU, 2013, 2014)[2]. The ongoing research described in this brief will complement these initiatives by improving natural disaster risk assessment.

Information requirements about risk and the kind of risk assessment applied may differ depending on the needs of the decision maker (Surminski et al., 2012). In this respect, a risk-layering approach can be identified as it is often observed that while high-probability/ low-impact risks can be dealt with through cost-effective risk reduction measures and insurance, low-probability/high-impact risk may require compensation by governments or public donors (Mechler et al., 2014). Partnerships can provide a solution for this upper layer. Obtaining reliable estimates of such extreme risks is important since private parties, like insurers, are often unwilling or unable to carry these risks and public policy makers need to find solutions for the extreme

[1] See http://www.wcdrr.org/preparatory/post2015
[2] See http://drr.jrc.ec.europa.eu/LossDataWorkshopOctober2014

portion of risks, such as reinsurance or compensation arrangements.

Assessments of natural hazard risks are needed for the current and future climate variability, so as to investigate and design policies that are able to cope with future risks and limit likely impacts of climate change. Because natural hazards and consequences of climate change are locally determined, local risk assessments are an important input for the design of adaptation policies (Aerts et al., 2014). On a broader scale, natural disaster risk assessments and how these are influenced by climate change can contribute to better understanding of the economic costs of climate change, of which current estimates often neglect extreme weather events (van den Bergh and Botzen, 2014).

The ENHANCE project

(Enhancing risk management partnerships for catastrophic natural disasters in Europe). The main goal of this project is to develop and analyse new multi-sector partnerships (MSPs) to reduce, prepare for or redistribute risk. A key part of the analysis comprises providing new risk scenarios and information in selected hazard cases in close collaboration with stakeholders. The project focusses on selected cases of high-profile catastrophic hazards in a variety of countries, including multi-hazard events (EU wide) as well heatwaves (EU wide), forest fires (Portugal), surface water flooding (UK, Italy, Romania), droughts (Spain, Italy), storm surges (Wadden Sea, Rotterdam), flash floods and landslides (Austria), and volcanic eruptions (Iceland with Europe-wide effects).

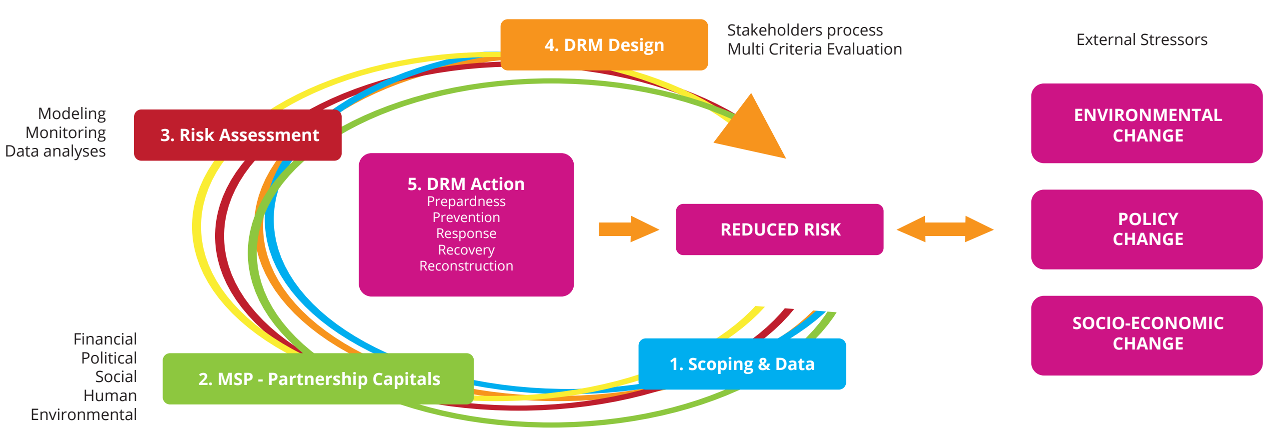
1 MAIN METHODS USED FOR RISK ASSESSMENTS

For a sound analysis of current and future natural hazard risks, it is important to understand dynamics of the underlying causes. For example, the projections of climate variability and change should ideally be based on an ensemble of (regional-) climate models that capture a broad spectrum of underlying uncertainties. Moreover, information on exposed economic assets as well as their vulnerability to hazards is needed. Combining the three dimensions is a non-trivial task, especially for the assessment of extremes. In ENHANCE a new approach was developed to avoid the underestimation of such low-probability/high-impact events.

Generally speaking, there are basically two approaches to arrive at distributions of natural disaster risks: namely statistical risk assessments and catastrophe models. One approach looks only at the past and estimates risk from historical loss data using extreme value theory (Embrechts et al., 1997). A fundamental challenge is how to model the rare phenomena that lie outside the range of any available observation. While much real world data follows approximately a normal distribution which implies that the estimation of distributional parameters can be done based

ENHANCE FRAMEWORK

Multi Sectoral Partnerships (MSP) & Disaster Risk Management (DRM)



on such assumptions, for natural hazard extremes the tails (rare outcomes) are much fatter than normal distributions predict. This is accounted for in extreme value theory according to which natural disaster risk distributions are estimated using, for example, Gumbel, Weibull or Frechet distributions. Typical steps in such an assessment are provided in ENHANCE for all case studies for which sufficient hazard or loss data is available.

A challenge with the statistical approach is that often few long historical records exist of low-probability/high-impact natural disaster risks, which is why catastrophe models are a commonly used alternative method. Catastrophe models are computer-based models that estimate the loss potential of natural disasters (Grossi and Kunreuther, 2005). This is usually done by overlaying the properties or assets at risk exposure module, such as classification of the CORINE land cover dataset and the potential sources of natural hazards (hazard module) in a specific geographical area with the use of Geographic Information Systems (GIS). A vulnerability module estimates the damage (e.g. of a flood) that occurs based on a function of the intensity hazard (e.g. inundation depth) and value of the exposure (e.g. the value of a flooded property). An alternative modelling method to catastrophe models are economic models which estimate the influence of a hazard on economic losses, such as reduced productivity, for specific sectors or the broader macro-economy. An example of such a model that has been developed for assessing drought risk in Spain is presented below.

Most catastrophe model techniques produce probabilistic risk estimates which are either based on specific hazard event scenarios, or are up-scaled from lower to higher spatial levels by summation of averages. However, with the former, the whole possible range of hazard impacts is neglected while in the latter, the detailed probability distribution of losses is lost and interdependencies of risks are neglected, such as the simultaneous occurrence of flood events in EU countries. This necessity to incorporate interdependencies for the correct risk assessment led to a new approach in ENHANCE which uses copulas to measure hazard extremes, including increasing dependencies of extreme risks. This is illustrated in the EU wide flood risk assessment explained below.

2 ILLUSTRATIVE EXAMPLES OF RISK ASSESSMENTS IN CASE STUDIES

EU-wide flood risk assessment for the solidarity fund

An EU-wide assessment of river flood risk has been undertaken to estimate current risk levels as well as how these may develop in the future as a result of climate and socio-economic change (Jongman et al., 2014). The basic method is a probabilistic catastrophe model of about 1,000 main river basins in the EU. This model estimates potential flood damage at a high spatial resolution (100 by 100 meter) using simulated daily river discharge data, extreme value analysis, spatial inundation modelling and an economic damage model, while considering existing flood-protection. A main advancement beyond the current state-of-the-art of this model is the use of copulas to account for dependencies of the hazard (flood probabilities) across river basins which can lead to large trans-national flood damages. Such dependencies were, for example, observed in 2013 when extreme weather caused flooding in nine countries in Central and Eastern Europe. The main idea behind the approach is the estimation of the correlation of the flood hazard between regions which is dependent on the given magnitude of the flood event itself. This approach reflects the observation that small flood events are more likely to be geographically limited than large (high impact) flood events. Via the use of proxies for the interdependencies of flood events in regions, large and extreme flood scenarios can be assessed and underestimation of losses is avoided.

Model results show that current average annual flood risk is about €5 billion which may increase up to €24 billion by 2050 because of socio-economic development and climate change (Jongman et al., 2014). These results have been used for a stress test of the EU Solidarity Fund that consists of a limited budget for financial aid to EU countries hit by a natural disaster. Jongman et al. (2014) estimate that by 2050 the fund's insolvency probability may be 80% higher, and that in addition the proportion of uninsured flood losses may increase.

The results of this risk assessment, which have been widely disseminated, highlight the need for the EU to consider enlarging the budget of the EU Solidarity Fund in the future and/or to expand the insurability of flood risk. How the latter can be achieved is subject to ongoing debate and research. A key challenge in this respect is how to link such financial compensation arrangements with incentives and policies for risk reduction (Surminski et al., 2015).

Flood risk analysis in London, UK

London faces a flood hazard that can be caused by surface water flooding as well as tidal flooding. The city is well protected against tidal floods, but protection standards for surface water flooding are relatively low. A catastrophe modelling approach is used to estimate potential flood damage caused by surface water flooding in the Greater London area. The flood hazard is modelled using hourly precipitation time-series data, which allow for a probabilistic analysis of extreme precipitation and surface water flood events with three return intervals. A detailed property level analysis estimates flood damage to residential buildings and contents. Potential future changes in flood risk by the years 2030 and 2050 as a result of climate change are derived using the most recent UK climate scenarios (UKCP09) and a stochastic Weather Generator that simulates future rainfall.

The London flood risk analysis is input for an Agent Based Model (ABM) which is a useful method for understanding systems and individual behaviour. This ABM has been developed to demonstrate the effects of flood risk and flood insurance on household wealth, potential shifts in inequality caused by flood damage and insurance (un)availability. Moreover, the ABM assesses the role of flood defenses and private flood risk mitigation measures for risk reduction, among other issues (Jenkins et al., 2015).

Preliminary results of the risk assessment show that economic damages caused by surface water flooding can be substantial, ranging from about £4.4 billion to £6 billion for 1 in 30 and 1 in 200 year events for a hypothetical extreme case, whereby the whole of Greater London would be affected on a given day. Expected annual damage is calculated as £103, £184 and £198 million/year for the baseline, 2030 high and 2050 high climate change scenarios respectively. The increase that results from climate change is mostly due to a higher severity of events when they do occur.

Results of the ABM highlight how development of properties in certain areas can become unsustainable, as well as the need for a consistent framework between different stakeholders to promote flood risk reduction (Jenkins et al., 2015). These results provide insights for the design of the new flood insurance scheme Flood Re, which is a public-private partnership of the government and private insurers for future affordability and availability of flood insurance.

Photo copyrights - Shutterstock

enhance
Partnership for Risk Reduction

Increased flood risk as a result of the water drainage disruption in the Po river basin district, Italy

The devastating earthquake that hit Northern Italy, especially the Emilia Romagna administrative region in May 2012, caused an estimated damage of over €13 billion and triggered the largest aid payment so far from the EU Solidarity Fund. Beyond the physical damage to property and productive capital, the earthquake damaged the extensive water drainage infrastructure. This infrastructure was developed over centuries to make the otherwise flood-prone areas, which are former wetlands, reclaimable for agricultural production and urban development. The provisional emergency plan consents controlled floods on agricultural and/or scarcely developed rural land, to protect medium-sized settlements and industrial facilities in areas prone to the exacerbated flood risk on the border between Emilia Romagna and Lombardy.

The risk assessment carried out by the ENHANCE consortium partners embraces both hazard characterisation and estimation of economic losses and damage. The hazard characterisation sets off with an analysis of the observed precipitation records in the study area, to shed light on the prevailing rainfall pattern and frequency of extreme events. The results in the form of intensity-duration-frequency curves serve as an input for the hydrological analysis that estimates the volume of drained water and timing of its outflow. With the help of the subsequent hydraulic analysis the flood-prone areas are delineated. The modelling workflow takes into account climate change induced shifts in extreme precipitation events, land use change contributing to greater surface flow, and disruption of the drainage network.

The economic analysis of flood damage and losses addresses the damage to tangible capital assets, including productive capital, fixed assets and consumer durable goods by means of stage-damage-curves; and an analysis of the production losses, in terms of flows of foregone production estimated through spatialized gross added value (GAV) and gross regional product. Whereas the GVA method captures the production losses within the affected areas, a regional general equilibrium model captures the multiple associations between production and consumption and, hence, is better suited to analyse localised impacts of medium-sized disasters.

The above risk assessment models have been applied and empirically tested in several revisited actual or simulated floods in the downstream part of the Po river basin. The economic damage estimate was instrumental for determining the cost-effectiveness of the control flood management strategy, and a just compensation for the inflicted damage. Furthermore, the economic risk assessment results will be used to inform cost recovery mechanisms for flood protection services by a land tax, and an insurance scheme against network disturbances similar to those that were caused by the 2012 earthquake.

Photo copyrights - Shutterstock

Drought risk in the Jucar, Spain

The Jucar river basin is one of the most vulnerable areas to drought in the western Mediterranean region. Major historic drought events happened in 1985-1988, 1990-1995, 2000-2002, and 2005-2008. As a result of climate change and growth in both population and water consumption, it is expected that extreme droughts will occur more often. Droughts negatively impact urban water, water quality in rivers and aquifers, river ecosystems and wetlands, agriculture and industry, cooling capacity of a nuclear power plant, and can trigger desertification and forest fires.

Drought risk has been typically addressed as a multi-stakeholder problem. A result of that is the creation of the Permanent Drought Commission for the management of drought situations. Effective drought risk management requires a coherent vision of the water necessities of the different water users. Moreover, insights are needed into the effectiveness of measures that reduce drought risk in terms of both water resources availability and economic impacts. This is done by using water management simulation and optimization models in Monte Carlo processes to study the possible future status of the basin. Economic instruments, such as water pricing policies and water markets, are studied by means of standalone hydroeconomic models within simulation and optimization approaches, through water demand functions for each user.

The decisions of the Permanent Drought Commission in emergency situations, as well as the decisions of the different reservoir withdrawal committees during normal situations, are supported mainly by operational drought indices and deterministic and probabilistic forecasts of reservoir storage evolution in the basin. Decision Support System Shells, such as AQUATOOL, have been successfully used in the real time management of the different basins dependent on the Jucar River Basin Agency.

Hydroeconomic models accommodate the integrated analysis of water supply, demand and infrastructure management at the river basin scale and have been used within the Jucar river basin to evaluate the potential of economic instruments in managing drought risk. Using monthly time-series over the period 1980-2001, a state-of-the-art hydroeconomic model simultaneously analyses engineering, hydrology and economic aspects of water resources management (Lopez-Nicolas, 2014; Pulido-Velazquez et al., 2013). Water scarcity costs are calculated as the economic losses due to water deliveries below the target demands, and both simulation and optimization approaches are used to obtain the marginal value of water at specific reservoirs in the system. The effectiveness of economic instruments in drought risk reduction is subsequently expressed in terms of a reduction in water scarcity cost during drought periods.

Preliminary results show that total water scarcity costs were €737 million in the period 1980-2001. These costs can be substantially reduced using economic instruments, such as water pricing policies which reduce costs by up to 60% and water markets which reduce costs up to 80%. These economic instruments result in an efficient allocation of resources during drought periods, with water moving to the highest-valued uses, and are thereby successful in decreasing drought risk. Successful implementation of such instruments, however, is also highly dependent on their acceptability among the different stakeholders within the Jucar river basin. Ongoing research within the ENHANCE project is, therefore, devoted to the development of multi-sector partnerships to harmonize these stakeholder opinions and thereby support the process of risk reduction and redistribution.

3 WAY FORWARD

Natural hazard risk assessments are becoming increasingly important for the design of policies that improve disaster resilience and promote adaptation to projected increases in natural disaster risks. It is especially relevant to obtain insights into the extreme risks posed by natural disaster events, namely the low probability of experiencing very high impacts. Evidently, such extreme risks are very difficult to estimate and inherently uncertain.

In the ENHANCE project new approaches for assessing natural disaster risks are being developed and applied to a rich variety of selected cases of high-profile catastrophic hazards in several EU countries. For example, by accounting for (geographical) interdependencies of hazards and risks using statistical methods, like copulas, better-quality estimates of low-probability-high impact risks can be obtained.

As the provided case study examples illustrate, the kind of risk assessment and its scale depend on how the results are used by decision makers. For example, the EU-wide flood risk assessment informs the design of the EU solidarity fund, while the local assessments of surface water flooding in the UK and drought risk in the Jucar provide useful information for local risk management policies, such as insurance and water pricing.

Next steps within **ENHANCE** are to further refine the estimation of multi-hazard risks and vulnerability of properties to disasters which depends on individual disaster preparedness, among other factors. Moreover, relevant stakeholders will be engaged in the risk estimation process and informed about the risk analysis results to enable the incorporation of risk information in decision-making about risk management in the cases.

Authors

Wouter Botzen [1], Reinhard Mechler[2], Jeroen Aerts[1], Stefan Hochrainer-Stigler[2], Anna Timonina[2], Anna Lorant[2], Ted Veldkamp[1], Paul Hudson[1], Katie Jenkins[3], Jaroslav Mysiak[4], Swenja Surminski[5], David Haro Monteagudo[6]

Affiliations

[1] Institute for Environmental Studies, VU University Amsterdam, The Netherlands

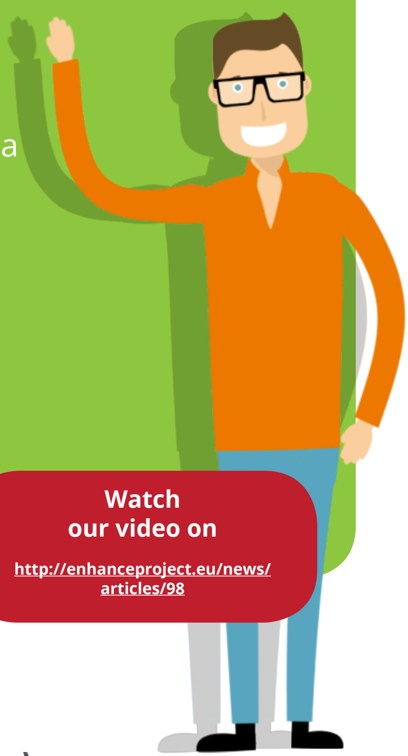
[2] IIASA—International Institute for Applied System Analysis, Austria

[3] Environmental Change Institute, University of Oxford, UK

[4] Fondazione Eni Enrico Mattei (FEEM), Italy

[5] The Grantham Research Institute on Climate Change and the Environment, London School of Economics, UK

[6] Instituto de Ingeniería del Agua y Medio Ambiente, Universitat Politècnica de València, Spain



Watch our video on

http://enhanceproject.eu/news/articles/98

For more information about the ENHANCE project:

Jeroen Aerts: jeroen.aerts@vu.nl (project coordinator)

Cédric Hananel: cedric.hananel@arctik.eu (project communications)

enhance
Partnership for Risk Reduction

REFERENCES

- Aerts, J.C.J.H., Botzen, W.J.W., Emanuel, K., Lin, N., De Moel, H., Michel-Kerjan, E. (2014). Evaluating flood resilience strategies for coastal mega-cities. Science, 344: 473-475.
- Botzen, W.J.W. (2013). Managing Extreme Climate Change Risks through Insurance. Cambridge University Press, Cambridge and New York, pp. 432.
- Embrechts, P., Klüppelberg, C., Mikosch, T. (2013) Modelling Extremal Events: for Insurance and Finance. 1st ed. 1997. Corr. 4th printing 2013. Springer, Berlin.
- European Union (2013). Recording disaster losses. Recommendations for a European approach. European Commission, Joint Research Center, and Institute for the Protection and Security of the Citizen. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC83743/lbna26111enn.pdf
- European Union (2014). Current status and best practices for disaster loss data recoding in EU member states. European Commission, Joint Research Center, and Institute for the Protection and Security of the Citizen. http://drr.jrc.ec.europa.eu/Portals/0/Loss/JRC%20SOTA%20Loss%20Report_11182014.pdf
- Grossi, P., Kunreuther, H.C. (2005). Catastrophe Modeling: A New Approach of Managing Risk. Springer, New York.
- IPCC (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Field C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M.D., Mach, K.J., Plattner, G.K., Allen, S.K., Tignor, M., Midgley, P.M. (eds.). Cambridge: Cambridge University Press.
- IPCC (2014). Impacts, Adaptation and Vulnerability. Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.
- Jenkens, K. Hall., J., Mechler, R., Lorant, A., Haer, T., Botzen, W., Aerts, J., Köhler, M., Pulido-Velaquez, M., Lopez-Nicolas, A. (2015). Key economic instruments for risk reduction and management for the case studies. ENHANCE deliverable 5.2.
- Jongman, B., Hochrainer-Stigler, S., Feyen, L., Aerts, J.C.J.H., Mechler, R., Botzen, W.J.W., Bouwer, L.M., Pflug, G., Rojas, R., Ward, P. (2014). Stress on disaster finance due to correlated flood extremes. Nature Climate Change, 4: 264-268.
- Lopez-Nicolas, A. (2014). Herramientas y modelos para el análisis de la aplicación de instrumentos económicos en la gestión de sistemas de recursos hídricos. Caso de estudio del sistema del río Júcar. Master's Thesis. Universitat Politècnica de València (in Spanish).
- Mechler, R., Bouwer, L.M., Linnerooth-Bayer, J., Hochrainer-Stigler, S., Aerts, J.C.J.H., Surminski, S., Williges, K. (2014). Managing unnatural disaster risk from climate extremes. Nature Climate Change, 4: 235–237
- Munich Re (2014). Natural catastrophes 2013: Analyses, assessments, positions. Topics GEO. Munich Re, Munich.
- Munich Re (2015). Loss events worldwide 2014: 10 costliest events ordered by insured losses. Munich Re Geo Risks Research, NatCatSERVICE.
- Pulido-Velazquez, M., Lopez-Nicolas, A., Harou J., Andreu J. (2013). Generalized DSS shell for developing simulation and optimization hydroeconomic models of complex water resources systems. EGU General Assembly 2013. Vienna.
- Surminski, S., Aerts, J.C.J.H., Botzen, W.J.W. Hudson, P., Mysiak, J., Perez-Blanco, D. (2015). Reflections on the current debate on how to link flood insurance and disaster risk reduction in the European Union. Natural Hazards, forthcoming.
- Surminski, S., Lopez, A., Birkmann, J., Welle, T. (2012). Current knowledge on relevant methodologies and data requirements as well as lessons learned and gaps identified at different levels, in assessing the risk of loss and damage associated with the adverse effects of climate change. Background paper. UNFCCC http://unfccc.int/files/adaptation/cancun_adaptation_framework/loss_and_damage/application/pdf/background_paper_full.pdf
- van den Bergh, J.C.J.M., Botzen, W.J.W. (2014). A lower bound to the social cost of CO2 emissions. Nature Climate Change, 4: 253-258.